FOREST SUSTAINABILITY IN THE FACE OF CLIMATE CHANGE AND INSECURITY: INNOVATIVE TECHNOLOGIES AND STRATEGIES

Proceedings of the

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ADDRESS OF THE PRESIDENT, ISTF-NIGERIA

The Governors, Our Royal Fathers, Distinguished guests, the Global President and EXCOs of ISTF, fellow environmental leaders, and experts, kindly permit me to stand on the existing protocol.

As the humble President of the International Society of Tropical Foresters Nigeria Chapter, I'm honored to welcome you to our third International Conference, “Kano 2025," with the theme "Forest Sustainability in the Face of Climate Change and Insecurity: Innovative Technologies and Strategies." I recognize the critical importance of this gathering.

Forests are vital ecosystems that support biodiversity, regulate the climate, and provide livelihoods and good health for millions of people worldwide. However, they face unprecedented threats from climate change, deforestation, and insecurity. Climate change exacerbates wildfires, droughts, and pests, while deforestation and degradation compromise ecosystem integrity. Insecurity and conflict also hinder conservation efforts, making it even more challenging to protect these precious resources, especially in terms of agroforestry.

Despite these challenges, we have reason to be hopeful. Today, we will explore innovative solutions that can help us address these pressing issues. Advanced monitoring technologies, such as new technologies, satellite imaging, and artificial intelligence, can enhance our ability to track forest health and detect threats. Sustainable forest management practices can promote ecosystem resilience, while climate-resilient reforestation strategies can help forests adapt to a changing climate. Community-led conservation initiatives and international cooperation can also be critical in protecting forests.

In this regard, I want to appreciate the President and Commander in Chief of the Armed Forces of Nigeria, His Excellency President Bola Ahmed Tinubu, GCFR for approving the establishment of a national forest guard initiative aimed at reclaiming Nigeria’s forests from terrorists, bandits, and criminal gangs. In the same vein, I want to thank the Executive Governor of Kano State, His Excellency Alh. Abba Kabir Yusuf for the successful conviction of illegal loggers in the state. Furthermore, I appreciate the Governo of Borno State, His Excellency Prof. Babagana Umara Zulum, CON, mni for being the first Governor to domicile the Great Green Wall as a State Agency and recently signing to law an Executive Order to prohibit indiscriminate felling of trees and mandate sanitation exercise with attract imprisonment and/or fine of up to ₦500,000 for defaulters. Also, to all our leaders who have made efforts towards environmental conservation and sustainability.

I like to express our deepest gratitude to the Vice Chancellor of Aliko Dangote University of Science and Technology, Wudil, Professor Musa Tukur Yakasai, and his management team, the ISTF-Global, ISTF-Nigeria Executives, NOC, LOC, the scientific committee, and all volunteers who worked tirelessly to make this conference a success. Your dedication and expertise have been invaluable.

We are proud to recognize the outstanding contributions of our award winners:

The first category is the Green Leadership Awards to

- His Excellency, Alh. Abba Kabir Yusuf, the Executive Governor of Kano State
- His Excellency, Prof. Babagana Umara Zulum, CON, mni FNSE, the Governor of Borno State

The second category is the Green Awards of Excellence to the following individuals, whose portfolios and impacts will be read during the award presentation:

- Prof Shadrach Olufemi Akindele
- Prof. Adeshola Olatunde Adepoju
- Prof Simon Shomkegh
- Dr. Ladipo Olajide
- Dr. Dahiru Muhammad Hashim
- Alh. Abdulhamid Umar,
- Alh. Bello Abba Yakasai
- Dr Mubarak Mahmud

Congratulations to each of you on your achievements. We look forward to seeing the impact of your work.

United, let's leverage technology, science, and collaboration to enhance forest resilience, promote sustainable development, and support climate change mitigation. I have no doubt that our discussions will yield impactful outcomes that will help shape the future of forest sustainability.

Thank you, and I wish you all a productive and inspiring conference.

Engr. Nkechinyere Clara Isienyi

ISTF-Nigeria President

ACCEPTANCE SPEECH AT THE 3RD ISTF-NIGERIA CONFERENCE 2025

Good morning, distinguished guests, colleagues, and friends. I am honored and humbled to receive the ISTF Green Award at this 3rd International Society of Tropical Foresters (ISTF) Nigeria Conference here in Kano. First and foremost, I want to thank the ISTF Nigeria Chapter for this tremendous honor. In particular, I am grateful to Engr. Nkechinyere C. Isienyi, President of the ISTF Nigeria Chapter, and Prof. Aminu Umar Fagge, Chairman of the Organizing Committee, for their leadership in organizing this event. I also thank everyone who worked behind the scenes to make this conference possible.

This award is deeply meaningful to me. On a personal level, it is a humbling affirmation that the work I have been passionate about – from the forests of Kano State to research labs abroad – has made a positive difference. On a professional level, it motivates me to continue pushing the boundaries of knowledge in sustainable forestry and environmental conservation. I see this honor not just as recognition of my efforts, but as a celebration of our shared commitment to a greener future, reinforcing the belief that innovation and dedication are key to addressing climate change and protecting natural resources.

A major reason I stand here today is an innovation I developed to measure tree height more easily and accurately. Determined to find a better way to measure tall trees without cumbersome instruments, I turned to a classic geometric principle – **Thales' Theorem** – to calculate height from a photograph, an approach that led to the creation of the **M-Tree** mobile application. I am proud to share that M-Tree's estimates are nearly identical to traditional measurements – about a **0.998** correlation with heights measured by a Suunto clinometer – yet this smartphone method works in a fraction of the time of conventional techniques and is far more accessible. By putting a powerful tool into anyone's hands, this innovation helps democratize forestry research and improve forest management.

However, the seed for this idea was planted many years ago during my undergraduate studies, in a course on **Forest Mensuration** taught by **Prof. Aminu Umar Fagge**. It was his passionate teaching, encouragement, and guidance that sparked the curiosity within me to explore more efficient ways of measuring trees. Prof. Fagge is not only a father figure to me but also a mentor who has shaped my academic journey in ways I could never fully express. His dedication to the field of forestry has inspired me to push the boundaries of what's possible and has been a guiding light throughout my career.

This conference's theme of **forest sustainability in the face of climate change and insecurity** is a powerful reminder of the challenges we face. Tropical forests are vital to our planet's health – they store carbon, preserve biodiversity, and support communities – yet they are under immense pressure from deforestation and climate change. To protect and manage these forests sustainably, we need accurate data and innovative tools. When we can monitor forest conditions efficiently, we can make smarter decisions about conservation and land use. Sustainable forestry isn't just about trees; it's about people and the planet.

None of these achievements would be possible alone. The success of the M-Tree project is a testament to the power of collaboration. I began this research at Aliko Dangote University of Science and Technology in Kano, and later refined it during my PhD at Université ParisSaclay in France, a collaboration that brought in new perspectives and expertise. I am grateful to my mentors and colleagues – here in Nigeria and abroad especially Laure Barthes – who guided

me and believed in this vision. Their support showed me that when we unite our efforts across disciplines and countries, we can solve complex problems. Collaboration among researchers, institutions, and nations is essential for tackling global challenges in forestry and climate change.

One of the goals of this award and conference is to inspire future generations of environmental leaders . To the young researchers and students here: I was once a student with a big idea that started right here in Kano, and that idea grew into something I could share with the world. If I can do it, you can too. **Believe in your ideas**, and be persistent in pursuing them. Seek out mentors, and never stop learning. Our field needs fresh perspectives, so don't be afraid to challenge old methods and explore new strategies – your creativity and dedication will drive positive change and help protect our forests.

In closing, I want to express my gratitude to the ISTF Nigeria Chapter for this honor. I am also grateful to my parents, my family and colleagues – everyone who has supported me on this journey. I share this award with all of them. I would be remiss if I did not also express my gratitude to Prof. Yusuf Bala Daraja. It was originally admitted in the Department of Chemistry when Prof. Daraja recognized my potential and suggested that I switch my course to Agriculture. During that conversation, he shared with me his belief that the future lay in forestry, a field that was still relatively untapped and full of opportunity. Those words stuck with me, and today, standing before you, I see the truth in his foresight.

This recognition is a reminder of our shared mission to advance sustainable forestry and protect the environment. It strengthens my resolve to continue this important work, and I hope it inspires all of us to redouble our efforts for a greener, more resilient world.

Thank you all for your attention, and thank you for this incredible honor.

Mubarak Mahmud

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MANAGING FOREST WATERSHED FOR CLIMATE RESILIENCE AND WATER SECURITY

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ABSTRACT

Forested watersheds serve as natural infrastructure that ensures clean and reliable water supplies. However, climate change exacerbates water-related challenges, including droughts, floods, and declining water quality. Deforestation and poor land management further degrade watershed functions, threatening water security for millions of people. Managing forest watersheds for climate resilience involves restoring and maintaining forests to enhance their capacity to regulate water cycles, withstand climate shocks, and sustain biodiversity. The Role of Forest Watersheds in Water Security and Climate Resilience involves: Water Regulation and Supply, Water Quality Protection, Carbon Sequestration and Climate Mitigation, Biodiversity and Ecosystem Stability. Moreover, other Strategies for Sustainable Forest Watershed Management include: Reforestation and Afforestation, Sustainable Land-Use Practices, Community-Based Management, Policy and Governance and Climate Adaptation Measures. As climate is gradually changing due to anthropogenic activities, and its consequences are felt all over, the Key Components of Climate Resilience are supposed to be understood through Risk Assessment, Preparedness & Planning, Adaptation, Equity & Inclusion, Ecosystem-based Approaches, Policy & Governance. Going by the definition of forest as an ecological unit in which there exist an interrelationship between the FAUNA and FLORA in their environment, this phenomenon has indicated that forest can influence how Forests can Improve Climate Resilience in the ecosystem through, Regulating Water Flow, **Reducing Disaster Risks**, **Cooling Microclimates** and **Carbon Sequestration. Clean water supply has been recognizing as important ecosystem services of forested watershed. Hence management of water security is paramount through: Reforestation and Afforestation, sustainable forest management and protected areas.**

DR. ISAH SULEMAN DUTSE

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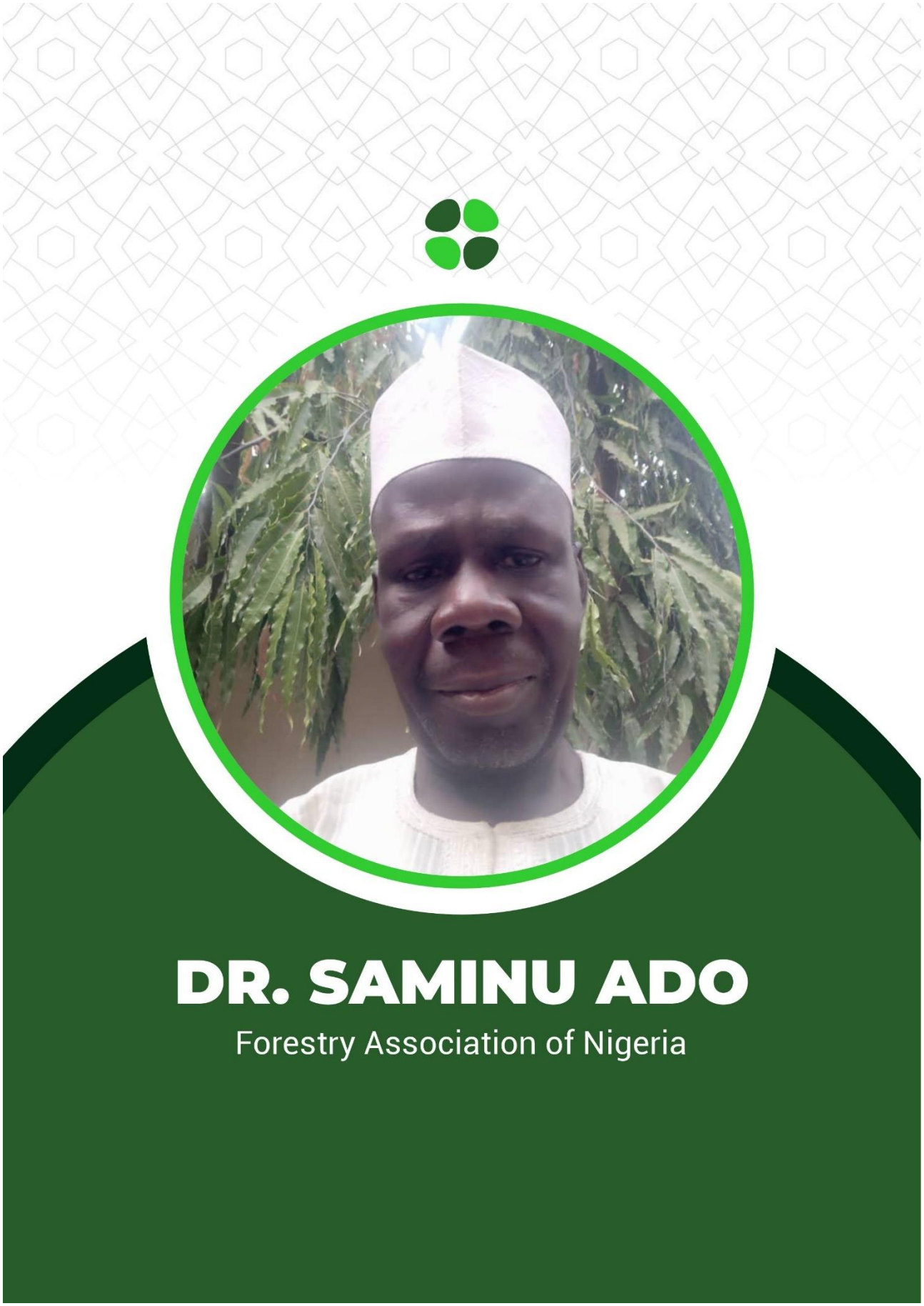
DR. SAMINU ADO
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INTEGRATING AGROFORESTRY SYSTEMS FOR FOOD SECURITY AND CLIMATE CHANGE ADAPTATION.

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INTRODUCTION:

Agroforestry practices have been promoted as sustainable land uses for increasingly intensifying farmers contributions to food security in many developing countries. Agroforestry practices are unique practices that contribute towards the realization of the objective of economy, conservation of resources and social acceptance of a given land. Agroforestry practices are designed to fit specific areas within the farm so as to meet the specific landowners set of objectives. For about twenty to thirty years projects have been established aiming to promote sustainable land use, rural development and food security among smallholder farmers, Susan, (2009). Susan, 2009, affirmed that, the level of successes and limitations of the various agroforestry systems in many areas has remained low (although success stories exist). Research continues as how to adapt proposed technologies to better fit within smallholders farming and livelihood systems and thus to encourage adoption. On-farm tree planting may also provide improved livelihood opportunities for lowland peasants, and contribute to sustainability in less environmentally vulnerable lowland areas.

The International Day of Forests, as observed annually on March 21, raises awareness of the importance of forests and their immense advantages for both our planet and humanity, Morsbach, (2025). The theme for 2025, was “Forests and Food”, and it emphasises on the vital link between the forests and the security of the global food systems. Forests contribute directly or indirectly to food availability. Agroforestry provides a wide variety of products and addresses the challenges related to food security and laying the foundation for a resilient agricultural landscape, Morsbach, (2025).

Azeez, et al (2005) added however that, in 2023, FAO reports that, around 757 million people faced hunger worldwide. To meet global food needs, it is crucial to recognise the role of forests in food security and fulfilling the nutritional needs of the global population. However, as the demand for food grows, the pressure on agricultural lands exacerbates.

What is Agroforestry?

Agroforestry is a sustainable land-use system approach to farming. It is a land management system that integrates trees, crops, and livestock to create productive eco-friendly and sustainable agricultural landscapes, Azeez, et al (2005). This practice combines agricultural and forestry techniques to maximize environmental, economic, and social benefits while maintaining the health of ecosystems. The practice enhances biodiversity, improves soil health, and offers economic, environmental, and social benefits.

It is considered a low-cost agricultural method of implementing different kinds of land management processes. This is done to reduce the heavy impact on natural land and forests due to agricultural requirements. It is also done to avoid destroying forests for the sake of producing crops for the sustainability of human civilization. The agroforestry systems also promote a greener economy due to the excellent promotion of renewable forest management and long-

term sustainability of small-scale farmers and other producers.

Agroforestry Key Criteria,

Four (4 "I") key criteria characterize agroforestry practices as summarize by the University of Missouri Center for Agroforestry are key to determine what is and what is not an agroforestry practice:

Intentional
Combinations of trees, crops, and/or livestock are intentionally designed, established, and/or managed to work together and yield multiple products and benefits, rather than as individual elements which may occur together but are managed separately. Agroforestry is neither monoculture farming, nor is it a mixture of monocultures.

Intensive

Agroforestry practices are created and intensively managed to maintain their productive and protective functions, and often involve cultural operations such as cultivation, fertilization, irrigation, pruning and thinning.

Integrated

Components are structurally and functionally combined into a single, integrated management unit tailored to meet the objectives of the landowner. Integration may be horizontal or vertical, above- or below-ground, simultaneous or sequential. Integration of multiple crops utilizes more of the productive capacity of the land and helps to balance economic production with resource conservation

Interactive

Agroforestry actively manipulates and utilizes the interactions among components to yield multiple harvestable products, while concurrently providing numerous conservation and ecological benefits.

Agroforestry Systems

Agroforestry systems are designed to mimic natural ecosystems by fostering symbiotic relationships between trees, crops, and animals. Unlike conventional monoculture farming, these systems prioritize sustainability and resource efficiency, ensuring long-term productivity while enhancing ecological health, World Bank. (1994).
As a climate-smart approach to farming, agroforestry systems address critical challenges like soil degradation, biodiversity loss, and climate change, making them an essential part of sustainable agriculture.

Key Features of Agroforestry Systems.

i. Integration: Combining trees with crops and livestock in a single system.
ii. Diversity: Using multiple species to enhance ecosystem resilience.
iii. Sustainability: Promoting natural resource conservation and long-term productivity.
iv. Synergy: Leveraging positive interactions between system components to boost yields and reduce resource competition

Different Systems of Agroforestry:
Cheikh Mbow et al, (2013) presented that, Agroforestry systems are designed to mimic natural ecosystems by fostering symbiotic relationships between trees, crops, and animals. Unlike conventional monoculture farming, these systems prioritize sustainability and resource efficiency, ensuring long-term productivity while enhancing ecological health.
As a climate-smart approach to farming, agroforestry systems address critical challenges like soil degradation, biodiversity loss, and climate change,

making them an essential part of sustainable agriculture according to ICRAF, (2021).

1. Agrisilvicultural System
If you split this term, you will find two different words, agriculture, and silviculture, merged together to give a name to this unique agroforestry practice. Silviculture means the practice of growing trees on a vast range of land and agriculture, the production of crops.

The Agrisilviculture system defines the conscious practice of growing trees and crops at the same time in a piece of land. It is done to generate more income and to make a sustainable choice for saving the forests. The method of concurrent production of crops and trees delivers exceptional economic benefits to the producers. Growing Acacia, Casuarinas, Cassia, Azadirachta, etc along with other food crops are common agroforestry examples one can find in village communities.

2. Silvopastoral System
It is a mode of agroforestry system where fodder plants are grown in pastures for livestock along with the production of trees and shrubs in the same piece of land. This is a unique practice where fast growing odder plants like leguminous herbs and grasses are grown. Including this list of plants, shrubs and trees are also grown that is not affected by the fodder plants. It helps the producers to create two different sources of the economy on a sustainable basis and increase his income. The fodder is grown for animal nutrition and other uses. Trees are grown for their leaves, fruits, wood, etc. Shrubs can be medicinal or of different kinds. The difference between this system and the Agrisilvicultural system is that the crops are not food but fodder for animal stock.

3.Agrosilvopastoral System
As per the term, we can conclude that this is the combination of agricultural practices with silviculture and pastoral growth. In this system, all three kinds of plantations are grown as food crops, animal fodder, and trees.

Agroforestry Practices:
Agroforestry practices are encouraged for maximum benefits by the practicing farmers. These practices according to ICRAF, (2021). include but not limited to the followings:
1. Silvopasture.
Combining trees with livestock grazing areas, silvopasture systems provide shade and forage for animals while improving soil health and reducing erosion.
2. Alley Cropping.
Rows of trees are planted alongside crops, optimizing land use and enhancing soil fertility through nutrient recycling.
3. Forest Farming.
Non-timber forest products like mushrooms, medicinal plants, and spices are cultivated under the canopy of trees, creating a layered production system.
4. Riparian Buffer.
Trees and shrubs are planted along waterways to reduce erosion, filter pollutants, and protect aquatic ecosystems.
5. Windbreak.
Trees are arranged in rows to protect crops from wind damage, conserve soil, and provide habitat for wildlife.
6. Home garden.
Diverse systems of trees, vegetables, fruits, and livestock are cultivated around homes, offering food security and income for smallholder farmers.
7. Integrated Aquaculture.
Trees are integrated with fish farming systems, where tree leaves provide shade and organic material, enhancing aquatic biodiversity and productivity.
8. Borderline planting.
Trees are planted around the boarder lines of plots of land, farmlands and other landscaped areas. These plants serve as a

demarcation of the land and gives ownership of the property.
9. Apiary – Beeking and honey production.
Trees are planted to serve as a source for the production of nectar for beekeeping.

Benefits of Agroforestry Systems
1. Environmental Benefits
- Improved Soil Health: Trees prevent erosion, enhance soil structure, and add organic matter.
- Carbon Sequestration: Agroforestry systems absorb carbon dioxide, helping mitigate climate change.
- Biodiversity Conservation: They create habitats for diverse species of plants, animals, and microorganisms.
- Water Conservation: Tree roots improve water infiltration and reduce surface runoff.

2. Economic Benefits
- Diversified Income: Farmers earn from multiple sources, such as timber, fruits, fodder, and livestock products.
- Reduced Costs: Natural pest control and nutrient cycling lower dependency on chemical inputs.
- Long-Term Returns: Timber and high-value tree products provide sustainable income over time.

3. Social Benefits
- Food Security: Agroforestry systems enhance food availability and diversity.
- Rural Livelihoods: They create jobs and support local economies in rural areas.
- Community Resilience: Diverse systems reduce vulnerability to market and climate shocks.

Challenges in Agroforestry Systems
1. Initial Investments: Establishing agroforestry systems requires significant resources for seedlings, labor, and infrastructure.
2. Knowledge and Skills: Farmers need technical expertise to design and manage agroforestry systems effectively.
3. Long Maturity Period: Many trees take years to mature, delaying economic returns for farmers.
4. Resources Competition: Improperly planned systems may lead to competition for sunlight, water, and nutrients between trees, crops, and livestock.

Design Principles for Agroforestry System
1. Site – Specific Planning: Tailor agroforestry systems to local conditions, including climate, soil type, and socio-economic context.
2. Synergistic Integrations: Ensure that trees, crops, and livestock complement each other rather than compete for resources.
3. Specific Selection: Choose tree and crop species that are compatible with the local environment and farming goals.
4. Sustainability: Prioritize practices that conserve resources, enhance biodiversity, and promote long-term productivity.
5. Regular Monitoring: Continuously evaluate the system to identify areas for improvement and ensure sustainable performance.

AGROFORESTRY SYSTEMS FOR FOOD SECURITY
Forests provide essential food resources – such as fruits, nuts, mushrooms, and wild edible plants – and contribute to improving crop cultivation and agricultural productivity by maintaining soil quality and reducing pests through natural ecological processes, Cheikh Mbow et al (2013). They also enhance food production, help in agriculture systems, and create a microclimate by providing shade and maintaining an optimum temperature that can protect crops from extreme weather conditions. When integrated into farming systems,

forest ecosystems can create the ecological conditions necessary for developing sustainable food production, thereby enhancing food security and meeting the growing demand for food.

Cheikh Mbow et al (2013) opined that, agroforestry systems can offer a more diversified and stable food supply by building resilience into food systems. By combining perennial and annual species, these systems buffer households against seasonal hunger and crop failure. Further, agroforestry enables smallholder farmers, who produce a majority of the world's food and often operate on degraded or marginal lands, to optimise their land use, diversify income streams, and enhance resilience to climate shocks, thereby strengthening food and livelihood security. This systemic approach should no longer be viewed as peripheral to agriculture but rather as integral to food system transformation.

Trees inside and outside agroforestry plots contribute to food security in Africa in the face of climate variability and change, Jalan Cifor (2013). More explicit inclusion of agroforestry and the integration of agriculture and forestry agendas in global initiatives on climate change adaptation and mitigation can increase their effectiveness, Jalan Cifor (2013).

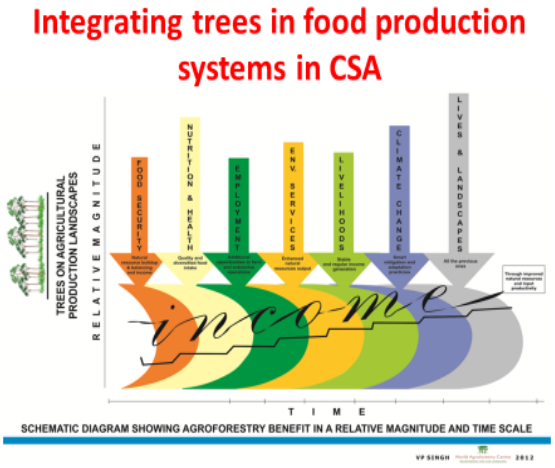
Different dimensions of food security

In a report titled: "Forests, Trees and Landscapes for Food Security and Nutrition" the International Union of Forest Research Organisations (IUFRO) underscores the need to apply an integrated landscape approach to achieve more sustainable agricultural systems. The report further highlights that agroforestry systems as an important sources of revenue for local people and governments, which can contribute to food supply.

As per World Food Summit 1996, food security is defined as when all people, at all times, have physical and economic access to sufficient safe and nutritious food that meets their dietary needs and food preferences for an active and healthy life.

The above definition of food security highlights the four dimensions of food security viz. food availability, food access, utilisation, and stability:

- Food availability is defined as the availability of adequate amounts of food of suitable quality. Agroforestry ensures a consistent supply of food throughout the year by incorporating a wider range of food options, including fruits, vegetables, and nuts.
- Food access covers adequate access to resources for acquiring appropriate foods for a nutritious diet. Diversified food sources in agroforestry can lead to a more balanced and nutritious diet.
- Food utilization covers the aspect of food utilization through adequate diet, clean water, and health care. In some regions, agroforestry systems often include medicinal plants that provide health benefits.
- Food stability focuses on access to adequate food at all times. Agroforestry practices help in preventing soil erosion and degradation, ensuring long-term agricultural productivity and food security.



Agroforestry products used as famine foods

A famine food or poverty food is any inexpensive or readily available food used to nourish people in times of hunger and starvation whether caused by extreme poverty such as during economic depression, by natural disasters such as drought or by war or genocide, (Abasse et al,.2009). Tree fruits and other edible tree products also constitute an important source of income and vitamins that complement needs of the farming population within the communities.

Agroforestry Production and livelihood creation

Agroforestry provide diverse products of livelihood importance to man. Significant proportion of people around the world depend directly or indirectly on products drived from agroforestry mainly or partly for their livelihoods activities. These may come in form of food, medicine, building materials, fuelwood or as a source of cash income.

Walsh, (2008) opined that, Agroforestry is a cost-effective means to enhance food security, while at the same time contributing to climate change adaptation and mitigation. Adoption of agroforestry depends on many management goals, drivers and contextual factors. In most cases, assets related to ecosystem services and to food security are the main motivating factors in agroforestry adoption Walsh, (Walsh, (2008).

Climate Change

Climate change is a long-term change in the average weather patterns that have come to define Earths local, regional and global climates. It is a long-term shifts in temperature and weather patterns. Climate change is one of the most complex challenges the world faces today. Climate change is one of the biggest challenges of our times. Its impact on human populations is not yet completely understood. Climate change has continuously affected our planet in the past causing biodiversity losses, collapses, or reshaping of societies and cultures, and it requires long periods for recovery and return to new "normal", albeit different, balances.

Agroforestry approach to climate change adaptation.

As highlighted by recent Intergovernmental Panel on Climate Change (IPCC) reports, agroforestry is a promising agro ecological approach to climate change adaptation because of the multitude of co-benefits that many agroforestry systems provides. This is, in addition to climate change adaptation, including synergies with climate change mitigation through carbon sequestration, enhanced food security and income opportunities, the provisioning of ecosystem services, and biodiversity conservation. Agroforestry systems are a transformative approach to sustainable agriculture, offering solutions to critical global challenges like food security, climate change, and biodiversity loss.

According to Mbow, (2014), Tree-based farming systems store carbon in soils and woody biomass, and they may also reduce greenhouse gas emissions from soils. The substantial carbon sequestration potential of agroforestry stems not so much from a

high carbon density, but from the large areas that are potentially suitable for agroforestry, including many degraded areas.

Compared to plantations of forestry species, carbon sequestration in agroforestry is relatively slow, so that payments through international carbon finance schemes may often not provide much incentive in low-potential regions, such as the West African Sahel, Mbow, (2014).

Climate change adaptation

Climate change adaptation is the process of adjusting to the effect of climate change both current and anticipated. Adaptation aims to moderate or avoid harm for people, and is usually done alongside climate change mitigation. Adaptation is action to help people adjust to the current and future effects of climate change.

Climate change Mitigation

Climate change Mitigation is action to reduce greenhouse gas emissions and limit the amount of warming our planet will experience. The final aim of mitigation is to stop the build-up of greenhouse gases in the atmosphere altogether, and begin drawing them down. The Paris Agreement of 2015 set worldwide targets for mitigation, with almost every country on Earth agreeing to zero out their greenhouse gas emissions in time to halt global warming at no more than 2° C, and ideally at no more than 1.5° C.

Extreme climate events (ECEs) and the role of agroforestry.

Extreme climate events are the consequences induced by climate change (e.g., floods, droughts, heat waves, storms). Unlike natural disasters, they are not occasional events in a stable system, whereas they are more frequent and extreme and long-lasting . However, there is still no consensus on the definition, since it is not clear how to classify their extremes, frequency, and impacts Mbow, (2014). Tipping points are self-reinforcing and interact with other systems triggering other tipping points, thus leading to a large shift that might be difficult to reverse. Critical situations induced by climate change can be considered a tipping point especially in rigid or already weakened systems. Several tipping points are currently active (such as deforestation, Arctic ice retreating, loss of biodiversity) and other potential ones have already been identified.

Global Warming.

Another topic that gained attention due to climate change is “global warming” . This is the relation between increased average surface temperature and violence. An increase in environmental temperature can impair the central nervous system and, therefore, psycho-physiological functions by affecting bio-chemicals (e.g., by altering the production of serotonin and dopamine) or by disrupting the homeostasis of thermoregulation.

Adaptation planning and the EU Adaptation Support Tool.

Adaptation planning usually draws on assessments of risks and vulnerability to climate change. It evaluates the relative benefits and costs of different measures to reduce these risks. Guidance has been developed that outline these general stages of an adaptation process, such as the EU Adaptation Support Tool.

1. Preparing the ground for adaptation
2. Assessing climate change risks and vulnerabilities
3. Identifying adaptation options
4. Assessing adaptation options
5. Implementing adaptation
6. Monitoring and evaluating adaptation

As of 2022, adaptation efforts have focused more on adaptation planning than on implementation. All regions and

sectors have made progress. However, the gaps between current needs and current implementation continues to grow, Becker, J. C (2011).

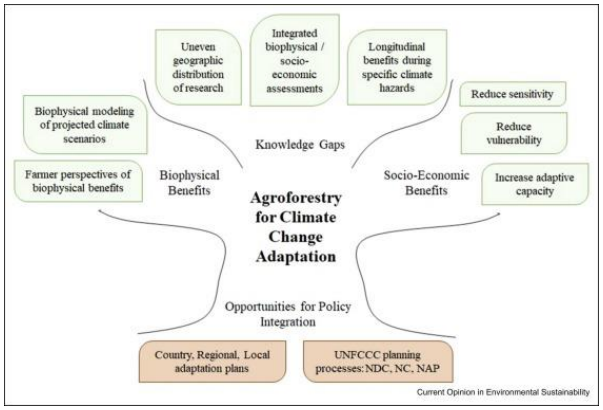


Figure 1. Summary of major concepts. This includes recent advances in our understanding of biophysical and socioeconomic benefits of agroforestry for adaptation, existing knowledge gaps, and opportunities for further integrating agroforestry into climate change adaptation policy.

Conclusion

There is a critical synergies as highlighted between agroforestry, the biodiversity supports nutrition, climte change adaptation and mitigation and its contribution to food safety, and stable livelihoods enhance well-being. The quantified agroforestry's dual impacts, linking ecological metrics like tree density and shade cover to direct food security and wellbieng outcomes is of paramount importance to the community`s survival.

Agroforestry is a cost-effective means to enhance food security, while at the same time contributing to climate change adaptation and mitigation. Adoption of agroforestry depends on many management goals, drivers and contextual factors and each needs to be appreciatedsingularly and collectively. In most cases, assets related to ecosystem services and to food security are the main motivating factors in agroforestry adoption Walsh, (2008).

With growing pressures from climate change and demographic development, farmers will need to produce significantly more food on less land. Climate change is likely to make it even harder for farmers to cope with these problems. Agroforestry is often considered a cost-effective strategy for climate change mitigation.

RECOMMENDATIONS

For agroforestry to continue providing basc products such as food and mitigate climate change, there is the need for the following:

1. Policymakers are urged to integrate agroforestry into health, agriculture, and climate strategies, incentivizing systems that deliver nutritional and ecological benefits.
2. There is the need for more extension services on Agroforestry to significantly improve yields and increase smallholder income, and enhanced climate resilience through microclimate cooling.
3. Enhance the political commitment to and interest in forestry and, to this end, "market" forestry better to politicians.
4. Review policies and strategies, including existing action plans, with a view to updating them and making them more realistic relative to the availability of domestic funding.
5. Assist farmers towards improving the generation of resources for their own contribution to forestry funding.
6. Better commercialization of products from plantations and, where appropriate, privatization as well as more effective collection of revenue
7. Seek to influence the opinion of key international decision-makers in the donor community in favour of agroforestry.

8. Future research need to prioritize longitudinal studies to understand long-term agroforestry impacts, particularly concerning smallholder farmers, and investigate the interactions between agroforestry, climate change, food and disease dynamics.

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SUB-THEME ONE

MANAGING FOREST WATERSHEDS FOR CLIMATE RESILIENCE AND WATER SECURITY

SIGNIFICANCE OF SUSTAINABLE WATERSHED MANAGEMENT ON CLIMATE CHANGE AND STABLE WATER SOURCE

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Abstract

Watershed management encompasses all procedural steps, goals and efforts that systematically avoid the deterioration of watersheds and water bodies to enhance and achieve their benefits continually. Climate change is real, affecting several facets of life and the environment. Therefore, this paper reviews the significance of sustainable watershed management on climate change and water sources to understand and establish the necessity of optimum management of the watershed. The paper examines the principles of watershed management, its causes of climate change, and its impacts and benefits. It is concluded that watersheds unequivocally affect the people's livelihood and quality of the environment, and a properly managed watershed can salvage ecosystem services from deterioration.

Keywords: Ecosystem, Deterioration, Sustainable management, Carbon emission,

Introduction

The role of watershed management on sustainable livelihood, climate resilience and secure water sources cannot be overemphasised. It has been established that every healthy ecosystem is endowed with a watershed (Asinwa and Olajuyibe, 2019). A watershed, which is not size-bound, refers to land area that receives and channels rainfall into creeks, streams, rivers and eventually discharges to larger water bodies such as the ocean or sea (Figure 1). Although not all water flows directly to the sea or other larger water bodies, rain infiltrates the ground to the groundwater whenever rain falls on dry ground (Kolokytha, 2022). It remains in the soil, eventually seeping into the nearest stream. Some water infiltrates deeper into underground reservoirs called aquifers (Narendra *et al*., 2021; Kolokytha, 2022). The use of land, the forest and water resources in such a way that plants and wildlife inhabiting the community are unaffected is called Watershed management (Kolokytha, 2022). It encompasses goals and all efforts and steps that reduce the amount of pesticides, herbicides and fertilisers that wash off farm fields to water bodies. A healthy watershed has a supply of clean water and rich soil, as it is evident in some studies that a larger volume of water in a watershed is not in the rivers and lakes, but in the soil itself (Asinwa and Olajuyigbe, 2019). Plants, especially trees, herbs, and grasses, in the higher parts of the watershed and along the banks of rivers and streams, improve the quality and quantity of groundwater (Asinwa and Olajuyigbe, 2019). Therefore, by protecting and conserving water, plants and soil, watershed management is very crucial. Invariably, watershed management is closely related to conservation, which is the strategic safeguarding of natural ecosystems, fauna and flora species, and all other resources from depletion/degradation (Iroye, 2010)

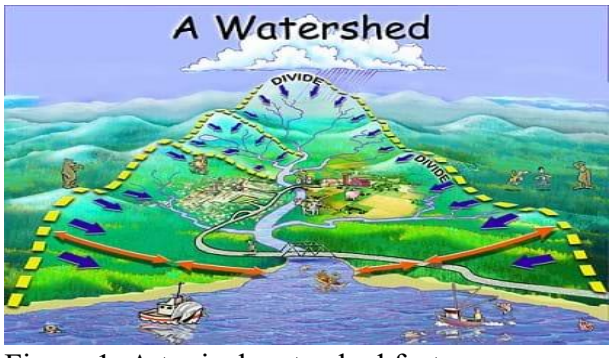

Figure 1: A typical watershed features
Source: National Science Foundation, 2022

Principles of Watershed Management

The strategic approach focusing on the health and functionality of water catchment areas is referred to as the watershed management

principle (Giri *et al*., 2012). This approach integrates management practices and principles, considering the social, economic, and environmental aspects vital for maintaining water resources and wetlands. The effective management ensures that water quality and availability meet the needs of both ecosystems and human populations (Giri *et al*., 2012). It entails formulating and implementing actions that manage and protect water resources within a watershed to balance economic, social, and environmental needs (USDA Forest Service, 2007).

These management principles include:

- Integrating landscape and water management to address watershed issues comprehensively.
- Ensuring stakeholders' active participation, including local communities, government agencies, and the private sector.
- Adopting a multi-disciplinary approach that combines economic, social, and environmental perspectives.
- Utilising scientific research and data for informed decision-making.
- Implementing adaptive management practices that can evolve with new challenges and information.

To ensure effective watershed management, strategies such as monitoring water quality, managing stormwater, restoring habitats, and engaging communities are to be implemented to address specific challenges and opportunities (Giri *et al*., 2012). For instance, community living near a river might implement watershed management strategies such as planting trees along riverbanks to prevent soil erosion, setting up rain gardens to absorb storm water, or organising clean-up events to remove litter from waterways. In addition to this, a watershed management implementation may involve local farmers, conservationists, and urban planners working together to create sustainable agricultural practices, such as contour ploughing and the establishment of buffer zones around water bodies, which reduce runoff and improve water quality, as well as provide other benefits.

Environmental benefits of watershed management include:

- Improve water quality by reducing pollution from runoff into rivers, streams and lakes.
- Enhancement of biodiversity by preserving and restoring natural habitats.
- Increase in groundwater recharge, which is essential for maintaining the water supply.
- Reducing the impact of flooding and soil erosion through landscape management and afforestation. Supporting sustainable agriculture and forestry practices that benefit the economy and the environment.

Importance of Sustainability in Watershed Management

The core pillar in watershed management that balances developmental goals with the long-term health of the watershed ecosystem is called sustainable watershed management (USDA Forest Service, 2007). It involves practices and strategies that are environmentally sound, economically feasible, and socially equitable.

Objectives of Sustainable watershed management entail:

- Conservation of natural resources within the watershed.
- Reduction of pollution and its environmental impacts.
- Promotion of practices that are resilient to climate change and other external pressures.
- Ensuring a stable water supply for future generations.
- Fostering stakeholder involvement and community engagement in watershed protection efforts.

Management Techniques Required for Effective Watershed Conservation

Several management techniques must be implemented to conserve watersheds effectively, so that each technique will target a specific aspect of watershed health. These techniques range from land use planning to the restoration of natural landscapes. For instance, installing green roofs on urban buildings is a technique that contributes to stormwater management. Green roofs (Figure 2) absorb rainfall, reducing runoff and decreasing the

pressure on sewer systems during heavy rains (Moutinho *et al.,* 2005).

Key techniques include:

- Land Use Planning and zoning to control development and mitigate its impact on watersheds.
- Restoration activities such as regeneration, restoration, reclamation and wetland rehabilitation to enhance natural functions.
- Stormwater management practices, including rain gardens and permeable pavements, can reduce runoff and pollution.
- Riverbank stabilisation to prevent erosion and protect aquatic habitats.
- Integrated watershed resources management that brings together stakeholders to address water, land, and related resources in a coordinated manner.

Figure 2: A green-roofed building towards sustainable watershed management
Source. Colorado Green Building Guild. 2025

Significance of Watershed

The success of watershed management efforts largely depends on the conditions and operational processes within the drainage basin of a particular watershed. Factors such as amount and distribution of rainfall, topography, soil types, existing vegetation cover and economic activities of farming and grazing practices largely dictate the level of benefits that will be acquired from a watershed. Several opportunities can be obtained from a healthy watershed, which absorbs rainfall and snow melt, controls erosion, recharges aquifers, sustains stream flows, filters pollutants from the air and runoff before they enter the waterways and provides critical habitat for fish and wildlife (Steffen *et al.,* 2015)**.** More to these, watersheds provide abundant recreational opportunities, help support local economies and provide an inexpensive source of drinking water and improve the quality of lives (USDA Forest Service, 2007). Forests in the watersheds serve as absorbers as they intercept runoff and reduce flooding during heavy rainfalls.

Meanwhile, the infiltrated water is released to streams in the dry season to maintain a steady flow. Roots of the trees and other vegetation make the soil more permeable to rainwater so that runoff is slower and more uniform than on cleared land. Consequently, streams in the watershed continue to flow in dry weather, and floods are minimised in rainy weather, with more positive impacts on climate change. (IUCN *et al*., 1991).

Concept of climate change

Climate change, which is a *long-term shift in temperatures and weather patterns, could be caused by natural and anthropogenic (or human) activities, with the latter being a major player globally over the last few decades*. (IPCC, 2007). Some natural drivers of climate change include volcanic eruptions and solar activity. In contrast, human activity in Nigeria, as in other parts of the world, has been a significant cause for the build-up of greenhouse gases (GHGs). Carbon dioxide (CO2) is one of the leading greenhouse gases and contributors to the greenhouse effect. When fossil fuels like coal, oil and gas are burnt, they release greenhouse gases. Anyadike, (2009) stated that through energy creating activities like heating homes and building, transportation and cooking, traveling (for example, by car, plane, bus and train), treating water to make it drinkable, heating it and piping it into homes, manufacturing, leakages from refrigerators, gas flaring, and bush burning, carbon dioxide is emitted into the atmosphere. Since the Industrial Revolution in the 18th century, the amount of carbon dioxide in the atmosphere has increased by 35%. The Niger Delta region of Nigeria is reported to have over one hundred and twenty-three gas flaring sites making Nigeria one of the highest emitters of greenhouse gases in Africa (FAO, 2012)

Causes of Climate Change

Deforestation

The phenomenon in which forests are indiscriminately removed without considering regeneration is called deforestation. It is a major contributor to climate change and accounts for

20 per cent of the world's carbon emissions (more than the entire transport sector produces) (IPCC, 2007). When trees are indiscriminately cut, fewer trees are left to absorb CO_2, and then it will build up in the atmosphere. With deforestation, GHGs such as carbon dioxide, carbon monoxide, methane, and nitrous oxide are released, offsetting the natural balance immensely, consequently contributing to global warming (Moutinho *et al.,* 2005). According to the FAO 2008), over the last fifteen years, when Nigeria's population was 190.7million, it was ranked first among ten countries with the highest rate of deforestation in the world in succession during the 1990-2000 and 2000-2010 Forestry Resources Assessment (FRA). The average annual deforestation rate was 3.3% for the period 1990-2010, so much that the country's forest coverage declined to about 10% of its total land area. Invariably, as the population hits 230 million in 2025 with a 2.08% annual increase, the deforestation would have drastically increased as well most importantly, the demand for fuel wood has been attributed as one of the major causes of the phenomenon. It therefore calls for concern, considering the importance of the watershed/forest in controlling the build-up of GHGs.

Upsurge in Population

As the world's population grows, more people will need food, livestock, and energy.

Nigeria has an estimated population of 170.1million at mid- 2012, projected to rise to 402.4million by mid-2050 (USAID, 2012). This has a corollary increasing demand for clearing the forest for land, processing of food, household, and industrial goods, which contribute to the emission of carbon and other hazardous substances to the environment. In most cases, population increase aggravates the following:

Urbanisation.

Urbanisation in developing countries like Nigeria is characterised by rapid population growth and migration to cities with conspicuous challenges and opportunities, including infrastructure strain, poverty, economic growth potential, etc. According to Etuk and Akpan-Ebe (2008), the continuous heavy toll from natural disasters is strongly associated with a large and growing population in risk-prone areas such as flood plains and low-lying coastal regions. More so, the struggle for space and food as a result of population increase has led immensely to the destruction of ecosystems through deforestation and fossil fuel exploitation. In 1970, the world's population was estimated at 3.7 billion; in 1995 (twenty-five years later), it went up to 5.1 billion. 90% of the population growth was within the developing countries (USAID, 2012). The resultant effect is environmental degradation.

Industrialisation

As the human population increased and spread over the earth, agriculture and natural ecosystems supported the growth of a civilisation and culture that increased knowledge and mastery over the natural world (USAID, 2012). The Industrial Revolution created the modern world with global commerce, factories, large cities, and pollution. The Industrial Revolution and its technological marvels were energised by fossil fuels, coal, and then oil and gas. Pollution and exploitation of bio-resources (forest) took on new dimensions as the industrial world turned to extracting raw materials from all over the world (Etuk and Akpan-Ebe, 2008).

Impacts of Climate Change

Nigeria is generally strongly predisposed to severe negative impacts of climate change due to its fragile economy, weak resilience and low adaptive capacity. Much of the sensitive economic resources are dependent on the climate. For example, the agriculture, forestry and fishing sectors employ up to 70% of the workforce (FAO, 2012). The heavy concentration of GDP generating industry in locations that are highly vulnerable to climate change - induced sea level rise, for example Lagos and the Niger Delta makes the country extremely vulnerable. The 2011 Climate Change Vulnerability Index (CCVI), published by the UK-based risk company, Maplecroft, classifies Nigeria as high risk (FGN, 2012).

Climate change is no longer a mirage in Nigeria due to the interplay of four main climate change-related hazards, viz.; increased temperature, change in amount, intensity, and pattern of rainfall, extreme weather events (including sea surge and drought), and sea level rise. These impacts are expected to increase in the future. Recent estimates suggest that, in the absence of adaptation, climate change could result in a loss

of between 2% and 11% of Nigeria's GDP by 2020, rising to between 6% and 30% by the year 2050 (FAO,2012).

Influence of Watershed on Climate change and sustainable water

Watersheds with healthy land cover and edaphic factors play a critical role in the earth's climate system, in several different ways. Most importantly for global climate change, the vegetation in the ecosystem captures carbon dioxide from the atmosphere and converts it, through photosynthesis, into living biomass: tree trunks, roots, branches and leaves. Soil resources in the watershed also store carbon absorbed through leaf litter, woody debris and roots. (Nguyen and Bui, 2000). Watershed also enhance nutrient cycling, erosion/sedimentation control, increased biodiversity, soil formation, wildlife movement corridors, water storage, water filtration, flood control, food, timber and recreation, reduced vulnerability to invasive species, the effects of climate change and other natural disasters. These goods and services are essential to our social, environmental and economic well-being (FAO, 2017). Specifically, watersheds provide an arrays of benefits that address issues of climate change and stable water sources. These include.

- Improvement of water quality: Watershed filters pollutants from point and nonpoint sources, promotes nutrient cycling, and helps retain sediment.
- Enhancing Carbon storage opportunities. A healthy watershed is capable of offsetting greenhouse gas emissions.
- Increased resilience in the face of climate change threats: Well-managed watersheds can be better adapted to more extreme weather patterns and changes in precipitation associated with climate change.
- Reduction of risk for invasive species colonisation: Naturally functioning ecosystems are more resilient and can favour indigenous species, helping them out-compete invasive species.
- **Reduced drinking water treatment and infrastructure costs:** Natural landscapes filter pollutants and protect water quality.
- **Reduced flood mitigation costs:** Floodplains and natural landscapes minimise the area and impacts of floods, reduce the burden on public drainage infrastructure and increase groundwater recharge.
- **Increased revenues and job opportunities.** Healthy watersheds provide ample opportunities for fishing, boating, swimming, hiking, biking, wildlife viewing and ecotourism.
- **Increased property values.** Housing near healthy watersheds has higher property values than those in or around degraded ecosystems and impaired waters.

Conclusion

Going by the definition, every landscape is characterised by watersheds, which unequivocally affect the people's livelihood and quality of the environment. A properly managed watershed salvages ecosystem services from deterioration and enhances physical, mental, social and economic benefits.

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PHYSICO-CHEMICAL PARAMETERS OF IKERE-GORGE, OYO STATE, NIGERIA

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Abstract

This study assessed the spatial and temporal variations in water quality parameters and their relationship with plankton abundance in Ikere-gorge, Iseyin, Oyo State, Nigeria, over 24 months (January 2017–December 2018). Monthly samples were collected from four stations, and standard methods were used to measure key physico-chemical parameters, including temperature, pH, dissolved oxygen, transparency, conductivity, total dissolved solids, hardness, alkalinity, nitrate, and phosphate. The results showed moderate fluctuations in water quality, with mean surface water temperature (28.14 ± 1.57°C), pH (6.50 ± 0.63), and dissolved oxygen (5.93 ± 0.29 mg/L) remaining within acceptable ecological thresholds. The water body was classified as mesotrophic, indicating moderate productivity and a potential risk of hypolimnetic anoxia. Pearson correlation analysis revealed significant relationships among several parameters: a negative correlation between temperature and dissolved oxygen, and between transparency and nutrient levels, while nutrient concentrations positively correlated with phytoplankton and zooplankton abundance. These findings highlight the importance of integrated water quality monitoring and management in maintaining ecosystem stability and sustaining aquatic productivity in the Ikere-gorge reservoir.

Keywords: Water quality, Plankton abundance, Ikere-gorge, Freshwater ecosystem, Mesotrophic, Nutrient dynamics, Dissolved oxygen, Nigeria

Introduction

Aquatic ecosystems are broadly categorised into marine, brackish, and freshwater systems, each distinguished by salinity and ecological characteristics. Freshwater ecosystems encompass rivers, streams, lakes, ponds, and reservoirs, are defined by their relatively low concentrations of dissolved salts and chemical compounds. These ecosystems are crucial in supporting diverse biological communities and maintaining ecological balance (Naiman *et al*., 2006). Freshwater, characterised by low ionic concentrations, particularly sodium and chloride, constitutes only about 0.01% of the earth's total water and covers approximately 0.8% of the planet's surface (Sigee, 2005). Despite this limited global presence, freshwater habitats are remarkably rich in biodiversity, supporting an estimated 100,000 species—approximately 6% of all described species worldwide (Sigee, 2005; Dudgeon *et al*., 2006).

The ecological integrity of freshwater ecosystems is influenced by various environmental variables, among which water quality is paramount. Freshwater bodies' physical and chemical characteristics determine the distribution, abundance, and survival of aquatic organisms, including fish and macroinvertebrates. Temperature, a critical water quality parameter, affects nearly all

biological and chemical processes within aquatic systems. As most freshwater organisms are poikilothermic, fluctuations in temperature can significantly impact their metabolism, reproduction, and survival. Hence, maintaining optimal water quality is essential for sustaining biodiversity and ecosystem services in freshwater habitats (Harrod *et al*., 2018; Gökçe, 2019).

Unfortunately, the quality of freshwater ecosystems is increasingly threatened by both natural and anthropogenic factors. Climate change, agricultural runoff, domestic waste discharge, and deforestation are key contributors to the degradation of water bodies. Such pressures are evident in ecosystems like Ikere-Gorge, where unchecked human activities have led to habitat modification and declining water quality. These disturbances often result in biodiversity loss, particularly for species with narrow habitat requirements, and a consequent decline in the ecological functions and services these systems provide (Dudgeon *et al*., 2006; Gökçe, 2019).

Freshwater ecosystems offer numerous ecosystem services critical to human well-being, including fisheries production, water purification, and hydropower generation. However, when these ecosystems are not adequately managed, the resulting degradation can compromise ecological health and human livelihoods (Amoo and Komolafe, 2018). The urgent need for effective conservation and management of freshwater systems cannot be overstated, especially in light of their socio-economic importance and vulnerability to pollution and climate impacts. Monitoring key physicochemical parameters provides a cost-effective approach to assessing ecological health and guiding interventions for pollution control and habitat conservation (Dirican, 2015; Gökçe, 2019).

Against this backdrop, the present study focuses on assessing physicochemical parameters in the Ikere-Gorge Reservoir, located in Iseyin, Oyo State, Nigeria. The aim is to evaluate the gorge's water quality and trophic status, intending to provide data that can inform sustainable management strategies for the conservation of aquatic resources in the region.

Materials and Methods

Study Area

Ikere-Gorge Reservoir is a multipurpose dam with a storage capacity of approximately 565 million cubic meters (mcm), situated in Ikere village, about 28 kilometres northeast of Iseyin, Oyo State, Nigeria. Geographically, the reservoir lies between latitudes 8°10′ and 8°20′N and longitudes 3°40′ and 3°50′E. The gorge receives its primary inflow from the Ogun River, with additional inputs from smaller tributaries such as the Amaka, Oowe, and Owu Rivers. The main watercourse originates from Sepeteri, approximately 40 kilometres from Ikere, passing through the communities of Asamu and Alagbon before reaching the reservoir.

Fishing activities are widespread across all twelve villages surrounding the reservoir. Four fishing villages were randomly selected for this study to serve as sampling locations. These include: Site A (Asamu): N 8º 13′ 54.828″, E 3º 47′ 00.696″; Site B (Agatu): N 8º 09′ 51.972″, E 3º 44′ 57.642″; Site C (Spillway): N 8º 11′ 53.760″, E 3º 44′ 51.810″; and Site D (Irawote): N 8º 14′ 01.170″, E 3º 42′ 47.802″. Water quality assessments were conducted monthly at each site to evaluate the physicochemical status of the reservoir.

Analysis of Water Quality Parameters

Water samples were collected using clean sampling bottles, and several parameters were measured directly on-site (in situ). A standard mercury-in-glass thermometer recorded air temperature in degrees Celsius (°C). Other in-situ parameters, including water temperature (°C), pH, electrical conductivity (µS/cm), and total dissolved solids (mg/L), were measured using a portable multi-parameter probe (Hanna Instruments, Model HI 98129).To determine dissolved oxygen (DO), water samples were chemically fixed in the field by adding 2 mL each of manganese sulfate, alkali-iodide azide, and concentrated sulfuric acid. Subsequent analysis in the laboratory was carried out using the Azide-Winkler titration method.

Water transparency was measured using a Secchi disc following the procedures described by Michaud (1991) and Offem *et al*. (2011). Total alkalinity was analysed using titrimetric methods

by standards outlined by the American Public Health Association (APHA, 1989). The concentration of phosphates (mg/L) was measured using the vanadomolybdo-phosphoric acid colourimetric method, while nitrate levels (mg/L) were determined using the salicylate colourimetric method, as described by Odulate (2010).

RESULTS AND DISCUSSION

Water Quality Parameters

The spatial mean monthly values of water quality parameters recorded for Ikere-gorge over 24 months (January 2017 to December 2018) are presented in Table 1. Although values varied slightly across the sampling sites, overall trends were evident. The monthly mean air temperature was 27.46±1.82ºC, with the lowest value (23.5ºC) recorded in Site D in January and the highest (31.0ºC) in Site B during May. Surface water temperature had a mean value of 28.14±1.57ºC, ranging from 25.0ºC in October to 32.0ºC in August, both recorded at Site A. The observed water temperature aligns with the findings of Olorunpomi *et al.* (2019). Still, it is notably higher than the values reported by Aiwerioghene and Ayoade (2016) for the same reservoir, suggesting the influence of climate change on thermal regimes. Harrod *et al.* (2018) reported a direct correlation between increasing air temperatures and freshwater warming. Lawani and Dirisu (2019) emphasised the role of climate change, vegetation loss, and water depth in shaping temperature fluctuations. Since temperature controls nearly all biological and chemical processes in freshwater ecosystems, such thermal variability has far-reaching ecological implications, particularly for fish physiology, distribution, and community dynamics.

The mean pH was 6.50±0.63, indicating a near-neutral environment. Values ranged from 5.5 in May (Site D) to 7.7 in February (Site A). The gorge was slightly acidic between May and August but remained near neutral during other months. These findings corroborate Olorunpomi *et al*. (2019), although slightly lower than those reported by Adeosun *et al*. (2009) and Amoo and Komolafe (2018) for Strabag Lake. The pH values fall within the acceptable tolerance range for fish (5.0–9.0), ensuring viable reproductive and survival conditions (Uttah *et al.,* 2008).

Water transparency averaged 1.34±0.12 m, with the lowest value of 1.1 m observed at Site C in May and the highest (1.6 m) at Site A in January and June. The reduced transparency compared to earlier studies (Aiwerioghene and Ayoade, 2016; Dan-kishiya and Chiaha, 2012) may be due to seasonal variation, sediment re-suspension, or anthropogenic activities. Local fishermen have noted a correlation between water clarity and fish catch, suggesting that low transparency may enhance catch efficiency due to decreased visual detection by fish.

The mean dissolved oxygen (DO) concentration was 5.93±0.29 mg/L, ranging from 5.2 mg/L (Site C) to 6.6 mg/L (Site B) in September. These values align with those of Aiwerioghene and Ayoade (2016). Still, they are lower than the findings of Olorunpomi *et al.* (2019) for the exact location and Ayoade *et al*. (2006) for other dams such as Asejire and Oyan. Nevertheless, the observed DO levels meet the 5 mg/L threshold suitable for most fish species (Uttah *et al*., 2008).

Electrical conductivity, ranging from 102.5 µS/cm in January (Site A) to 158.0 µS/cm in July (Site B), had a mean of 130.59±7.59 µS/cm. This range is lower than values reported for Awba Dam (Anago *et al*., 2013) but higher than those recorded in River Niger at Onitsha (Arazu and Ogbeibu, 2017). Conductivity is influenced by the catchment area's temperature, rainfall, and geological features (Lawani and Dirisu, 2019).

Total dissolved solids (TDS) varied between 53.5 mg/L and 80.0 mg/L, with a mean of 67.67±4.37 mg/L. It falls within the range observed by Dimowo (2013) in the River Ogun. Total hardness, ranging from 31.7 mg/L to 85.9 mg/L, averaged 56.70±15.76 mg/L, indicating that Ikere-gorge water is moderately complex (EPA, 2001). These values are, however, lower than those reported for Çamlıgöze Dam, Turkey (Dirican, 2015) and Ona River in Ibadan (Andem *et al.,* 2012).

Table 1: Mean monthly water quality parameters of Ikere-gorge, Iseyin, Oyo State, Nigeria (Jan. 2017 – Dec. 2018)

Water Quality	Site A	Site B	Site C	Site D	Pooled Mean
Air Temp	27.46±1.96	27.54±2.05	27.67±1.99	27.17±1.87	27.46±1.82
Water temp	28.21±2.15	28.13±1.69	28.08±1.61	28.13±1.54	28.14±1.57
pH	6.60±0.64	6.42±0.61	6.40±0.52	6.55±0.83	6.50±0.63
Trans (m)	1.39±0.13	1.30±0.15	1.34±0.13	1.35±0.15	1.34±0.12
DO (mg/L)	5.90±0.33	5.95±0.45	5.92±0.46	5.94±0.37	5.93±0.29
Cond (µS/cm)	127.88±12.13	138.79±14.18	124.46±12.0	131.25±6.68	130.59±7.59
TDS (mg/L)	67.38±5.54	70.92±7.38	64.92±7.17	67.46±3.33	67.67±4.37
T.Hard (mg/L)	56.77±16.27	54.30±15.22	59.01±16.28	56.74±16.02	56.70±15.76
T.Alka (mg/L)	60.26±10.55	58.17±10.18	59.01±9.40	58.44±8.95	58.97±9.53
Phos (mg/L)	2.20±0.62	2.13±0.71	2.50±0.69	2.05±0.71	2.22±0.67
Nitrate (mg/L)	2.77±1.26	2.83±1.13	2.95±1.29	3.08±1.27	2.90±1.23

Air Temp- Air temperature (ºC), Water Temp – Water temperature (ºC), Trans – Transparency (m), DO – Dissolved oxygen (mg/L), Cond – Conductivity(µS/cm), TDS – Total dissolved solids (mg/L), THard– Total hardness (mg/L), TAlka – Alkalinity (mg/L), Phos – Phosphate (µg/L), Nitrate (µg/L).

Total alkalinity averaged 58.97±9.53 mg/L, ranging from 42.0 mg/L (Site B) to 79.75 mg/L (Site A). These values are higher than those recorded by Arazu and Ogbeibu (2017) for River Niger and Imoobe (2011) for Okhuo River, but lower than those found in Ona River (Andem *et al.,* 2012). The phosphate concentration ranged from 1.1 µg/L to 3.7 µg/L, with a mean of 2.22±0.67 µg/L, and was higher than those reported by Arazu and Ogbeibu (2017) for River Niger. Nitrate levels ranged from 1.2 µg/L to 5.3 µg/L with a mean of 2.90±1.23 µg/L, exceeding values previously observed by Aiwerioghene and Ayoade (2016). According to Lu (2012), the trophic status of Ikere-gorge can be classified as mesotrophic (Stage 2), characterised by moderate water clarity and increasing likelihood of anoxic conditions in the hypolimnion.

Correlation Between Water Quality and Plankton Abundance

Pearson correlation analysis (Table 2) revealed key interactions between water quality parameters and plankton communities. Air temperature negatively correlated with water temperature and transparency, but positively with phosphate. A significant negative relationship ($p<0.05$) was observed between surface water temperature and dissolved oxygen, affirming the inverse association between thermal and oxygen regimes. This finding is consistent with studies by Odulate *et al.* (2017), Valenti *et al*. (2017), and Portinho *et al.* (2016), which demonstrated that elevated temperatures reduce oxygen solubility in aquatic systems.

pH was negatively correlated with phytoplankton abundance ($p<0.05$), suggesting that lower pH values may promote phytoplankton productivity. Transparency exhibited a significant negative correlation with both total hardness and phytoplankton abundance ($p<0.05$) and with phosphate and nitrate levels. It indicates that higher nutrient levels enhance phytoplankton growth, increasing turbidity. Arazu and Ogbeibu (2017) reported that transparency is closely linked to productivity and influenced by suspended and dissolved materials.

Dissolved oxygen showed a positive relationship with phosphate ($p<0.05$), possibly reflecting the influence of nutrient enrichment on algal productivity and oxygen dynamics. Electrical conductivity correlated positively with TDS, total hardness, and zooplankton abundance at the 0.01 significance level, and with total alkalinity and phytoplankton at $p<0.05$. Similarly, TDS showed strong positive associations with total hardness, alkalinity, and zooplankton abundance ($p<0.01$), reflecting the interconnectedness of mineral content and biological productivity.

Total hardness correlated positively with alkalinity and nitrate at $p<0.01$, while alkalinity was significantly associated with nitrate and zooplankton ($p<0.05$). Phosphate and nitrate also showed a positive correlation ($p<0.05$), with nitrate significantly associated with both phytoplankton and zooplankton abundance ($p<0.05$). Finally, phytoplankton and zooplankton populations exhibited a positive correlation ($p<0.05$), indicating a bottom-up trophic link whereby increased primary production supports higher zooplankton biomass. These interactions demonstrate that plankton abundance in Ikere-gorge is influenced by a complex interplay of physicochemical parameters, especially nutrients (phosphate, nitrate), temperature, and transparency, which mediate ecosystem productivity and trophic dynamics.

Table 2: Correlation Matrix of Water Quality Parameters of Ikere-gorge, Iseyin, Oyo State, Nigeria (Jan. 2017 – Dec. 2018)

	AirT	WaterT	pH	Transp	DO	Cond	TDS	T.Hard	T.Alk	Phosp	Nitrat	NP	NZ
AirTemp	1												
Water.T	-0.64*	1											
pH	-0.36	-0.11	1										
Transp	-0.73**	0.34	0.41	1									
DO	0.43	-0.58*	0.40	-0.42	1								
Cond	-0.33	0.23	0.37	0.40	-0.47	1							
TDS	-0.19	0.46	0.26	-0.31	-0.47	0.94**	1						
T.Hard	0.072	-0.09	-0.25	-0.66*	0.07	0.73**	0.724**	1					
T.Alk	-0.33	0.37	-0.18	-0.30	-0.09	0.64*	0.729**	0.81**	1				
Phosph	0.65*	-0.30	-0.27	-0.87**	0.59*	0.04	0.06	0.54	0.25	1			
Nitrate	0.49	-0.24	-0.30	-0.74**	0.27	0.49	0.45	0.76**	0.61*	0.67*	1		
NP	0.51	0.06	-0.68*	-0.69*	-0.10	0.61*	0.55	0.48	0.31	0.45	0.59*	1	
NZ	0.22	0.12	-0.45	-0.53	-0.21	0.80**	0.82**	0.71*	0.60*	0.34	0.64*	0 .71**	1

AirT- Air temperature (ºC), WaterT – Water temperature (ºC), Transp – Transparency (m), DO – Dissolved oxygen (mg/L), Cond – Conductivity(mg/L), TDS – Total dissolved solids (mg/L), THard– Total hardness (mg/L), TAlk – Alkalinity (mg/L), Phosp – Phosphate (mg/L), nitrate (mg/L), NP – Number of Phytoplankton /ml, NZ – Number of Zooplankton/ml. * = 0.05; ** = 0.01

Conclusion

This study provides a comprehensive assessment of the spatial and temporal variation in water quality parameters of Ikere-gorge over two years and their influence on plankton abundance. The findings revealed that most water quality parameters fluctuated moderately within acceptable limits for freshwater ecosystems and aquaculture practices, including temperature, pH, dissolved oxygen, and nutrient levels. The dam exhibited near-neutral pH, moderate turbidity, and mesotrophic conditions, all critical indicators of ecological health. The observed correlations between water quality variables and plankton abundance highlight the dynamic interactions within the aquatic ecosystem. Notably, increases in nutrient concentrations (nitrate and phosphate) were associated with enhanced plankton productivity. At the same time, higher water temperatures corresponded with lower dissolved oxygen levels—an ecological pattern consistent with climate-driven impacts and anthropogenic pressures. These insights underscore the importance of regular water quality monitoring and integrated watershed management to safeguard the ecological integrity and productivity of Ikere Gorge. Ultimately, this study contributes valuable baseline data for future ecological assessments and supports informed decision-making for sustainable fisheries management and conservation planning within the region.

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ABUNDANCE, DISTRIBUTION AND DIVERSITY OF AQUATIC PLANTS OF IKERE-GORGE DAM, OYO STATE, NIGERIA

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Abstract

This study investigates aquatic macrophytes' diversity, composition, and distribution in Ikere-Gorge Dam, Iseyin, Oyo State, Nigeria. Aquatic plant species, including floating, emergent, and submerged forms, were surveyed following standard protocol. Aquatic plant samples were collected from the dam using a canoe, which navigated the littoral zone in a zigzag pattern to ensure thorough coverage. A total of 23 species belonging to 13 families were identified across four sampling sites. The family Cyperaceae recorded the highest number of species (4), followed by Nymphaeaceae and Poaceae with three species each. Emergent plants accounted for most (58%) of identified species, while floating and submerged forms represented 29% and 13%, respectively. *Salvinia molesta*, a floating invasive species, exhibited the highest abundance across all sites, whereas *Najas guadalupensis*, a submerged species, had the lowest relative density (0.27). Diversity indices revealed a gamma diversity 23, with alpha diversity ranging from 20 to 22 across sites. Shannon-Wiener index values ranged from 2.71 to 2.75, indicating moderate species diversity. The dominance of emergent vegetation, particularly from the *Cyperaceae* and *Poaceae* families, indicates progressive shoreline colonisation likely driven by siltation and nutrient accumulation. The widespread occurrence of invasive species such as *Salvinia molesta* poses a potential threat to native biodiversity. At the same time, the low abundance of submerged macrophytes like *Najas guadalupensis* reflects possible habitat alteration or competitive exclusion. The moderate species diversity observed across the sites underscores the ecological significance of Ikere-Gorge as a habitat for diverse aquatic flora.

Keywords: Aquatic macrophytes, Species diversity, Emergent plants, Ikere-Gorge, Invasive species, Submerged vegetation

Introduction

Freshwater biodiversity encompasses all species that rely on freshwater ecosystems for one or more stages of their life cycles, including a wide array of organisms such as plants, insects, amphibians, reptiles, fish, crustaceans, mammals, and birds (USAID, 2015). Similarly, the Convention on Biological Diversity (CBD, 2016) defines freshwater biodiversity as the component of biodiversity associated explicitly with inland water systems. However, due to the fundamental

reliance of all terrestrial life on freshwater, the distinction between aquatic and terrestrial ecosystems often becomes indistinct. At the species level, freshwater biodiversity includes all organisms that utilise freshwater habitats beyond mere consumption, such as breeding, shelter, or other ecological functions. In addition to fully aquatic organisms like fish, this includes numerous semi-aquatic and terrestrial species, such as waterbirds, hippopotamuses, crocodiles, beavers, as well as riparian and seasonally inundated plants like mangroves and flooded forests. Amphibians, for instance, predominantly depend on freshwater bodies for breeding.

Aquatic plants are those with photosynthetic organs that are either permanently or periodically submerged or floating in water and visible to the naked eye. These plants are vital to freshwater ecosystems and contribute significantly to overall aquatic biodiversity. When in moderate abundance, their presence enhances fish production by offering shelter, breeding sites, and food sources for various fish species and other aquatic organisms (Dienye, 2015). According to Valley *et al*. (2014), aquatic vegetation plays multiple ecological roles, including supporting primary production, stabilising sediments, maintaining water transparency, and providing high-quality habitats for zooplankton, macroinvertebrates, and diverse fish species.

Despite their ecological value, aquatic plants can become problematic when they proliferate excessively, posing challenges to freshwater ecosystem management and leading to ecological and economic losses (Narasimha and Benarjee, 2016). Research on aquatic vegetation, particularly within the Ikere Gorge dam ecosystem, remains limited. This study aims to fill that gap by providing baseline data on the species composition, abundance, and diversity of aquatic plants in the Ikere Gorge dam. Such information is crucial for informed management strategies that optimise the ecological benefits of aquatic plants while mitigating their potential adverse effects. Moreover, understanding the aquatic flora of the region is essential for enhancing habitat quality, food availability, and nursery functions for various aquatic organisms.

Materials and Methods

Study Area

The Ikere Gorge dam is a multipurpose dam in Ikere village, approximately 28 km northeast of Iseyin in Oyo State, Nigeria. The dam lies between latitudes 8°10′ and 8°20′N and longitudes 3°40′ and 3°50′E (Figure 1). Its surrounding landscape features a mix of savanna and forest vegetation, including aquatic grasses and shrubs along the shoreline. The dam is subject to frequent wind-induced water currents, which can generate significant wave activity, particularly during the rainy season (Kehinde and Ayoade, 2012). The water body originates from Sepeteri, about 40 km away, and flows through Asamu and Alagbon into the Ikere Gorge dam. The Ogun River is the primary tributary, with Rivers Amaka, Oowe, and Owu as secondary tributaries.

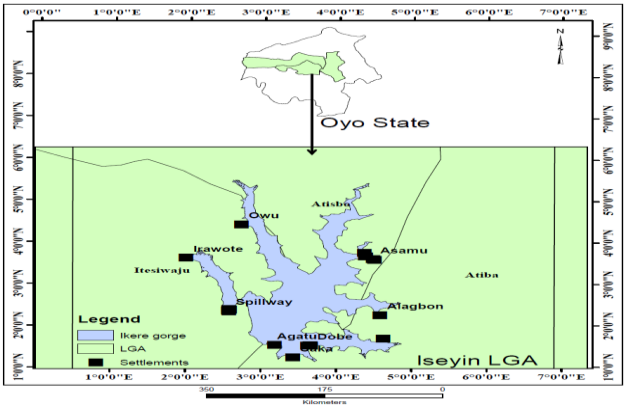

Figure 1: Map of Ikere Gorge Dam, Oyo State, Nigeria

Sampling Sites and Design

The Ikere Gorge dam hosts 12 fishing villages. To ensure representative sampling, a stratified random sampling technique was employed. The fishing villages were categorised into four strata based on their geographic locations and relative

proximity. One fishing village was randomly selected from each stratum, resulting in four sampling sites:

i. **Site A: Asamu** (N 8º 13′ 54.828″ E 3º 47′ 00.696″)
ii. **Site B: Agatu** (N 8º 09′ 51.972″ E 3º 44′ 57.642″)
iii. **Site C: Spillway** (N 8º 11′ 53.760″ E 3º 44′ 51.810″)
iv. **Site D: Irawote** (N 8º 14′ 01.170″ E 3º 42′ 47.802″)

The coordinates of all sampling sites and villages were recorded using a Global Positioning System (GPS). Field sampling was conducted monthly over 24 months, from January 2021 to December 2023. Each site was sampled four consecutive days during the first week of every month.

Sampling, Preservation, and Identification of Aquatic Plant Species

Aquatic plant species, including floating, emergent, and submerged forms, were surveyed following the protocol outlined by Adesina *et al*. (2011). A 10 m × 10 m sampling plot was established in each selected fishing village to capture data from littoral and open water zones. With the assistance of local fishermen, aquatic plant samples were collected from the dam using a canoe, which navigated the littoral zone in a zigzag pattern to ensure thorough coverage. Both submerged and emergent plant species along the shoreline were collected. Observations on water depth were also recorded during sampling.

Specimens, including flowers, seeds, and roots, were handpicked or gathered with sampling rakes. The collected samples were rinsed and preserved using plant presses. Subsequently, the samples were taken to the Forestry Research Institute of Nigeria (FRIN) for proper taxonomic identification. Plant species identification was conducted using standard identification keys provided by Akobundu and Agyakwa (1998) and supplemented with web-based botanical manuals. GPS coordinates were recorded at each location where plant samples were obtained.

Data Analysis

Relative density

It is the proportional contribution of individual aquatic species to the total population in the sample. It was computed with the formula:

$$RD = Si / N * 100 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

Where:

RD – Relative density
Si – Population of individual species
N – Total population of species.

Frequency of occurrence

It is the number of plots where individual aquatic plant species were recorded among the sampling plots. Hence, it was calculated using the formula of Lare-Tier II (2010):

$$S / N \times 100 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

Where:

S – The number of points where the species is present
N – The total number of plots surveyed

Diversity indices

Different diversity indices determined Aquatic diversity using Palaeontological Statistics (PAST) and the R statistical package (Odulate *et al*. 2017; Hammer *et al.* 2001).

i. Shannon-Weiner Diversity Index (Mörsdorf, 2015)

$$H = -\Sigma\ Pi \ln Pi \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

Where:

H = Shannon–Weiner index (the uncertainty of species identity)
Pi= ni/N
ni = number of individuals of each species in the sample
N = Total number of individuals of all species in the sample

ii. Simpson's Index of Dominance (Hossain *et al*. 2012).

$$\lambda = \sum p_i^2$$

$$\lambda = \frac{\sum ni\,(ni - 1)}{N\,(N - 1)} \quad \ldots\ldots (4)$$

The value of **λ** ranges between 0 and 1.

When λ is:

0 – Infinite diversity (maximum or highest diversity)

1 – No diversity in the population.

iii. **Simpson's Index of Diversity** (D**)** is also called the Gini coefficient.

$$\mathbf{D = 1 - \frac{\sum ni\,(ni - 1)}{N\,(N - 1)}} = 1 - \boldsymbol{\lambda} \quad \ldots\ldots\ldots\ldots (5)$$

Likewise, the value of this index (D) is between 0 and 1.

When D is:

0 – no diversity in the population

1 – Infinite diversity (Highest or maximum) diversity

Results and Discussion

23 aquatic plant species representing 13 families were identified in Ikere-Gorge dam, Iseyin, Oyo State, Nigeria. The family Cyperaceae recorded the highest number of species (4): *Carex autro-africana*, *Cyperus dives*, *Rynchospora corymbosa*, and *Scirpus articulatus*. It was followed by Nymphaeaceae and Poaceae, each with three species. The Nymphaeaceae species were *Nymphaea caerulea*, *Nymphaea lotus*, and *Nymphaea nouchali*, while the Poaceae species included *Echinochloa pyramidalis*, *Andropogon tectorum*, and *Phragmites australis*. Other families, such as Convolvulaceae, Onagraceae, and Polygonaceae, had two species each, while Araceae, Ceratophyllaceae, Fabaceae, Hydrocharitaceae, Salviniaceae, and Sphenocleaceae were represented by a single species each (Table 1).

Regarding life-form distribution (Table 1 and Figure 2), 58% of the aquatic plants were *emergent*, 29% *floating*, and *13% submerged*. This predominance of emergent macrophytes suggests encroachment of the littoral zone, potentially caused by siltation and accumulation of detritus from surrounding catchment areas. This observation aligns with findings from Ghosh and Biswas (2015), Ahmad *et al*. (2015), and Adesina *et al*. (2011), who also reported high proportions of emergent vegetation in disturbed freshwater ecosystems.

Table 1: Checklist of species composition of aquatic plants of Ikere-gorge Dam, Iseyin

Family	Plant Species	Common name	Ecology
Araceae	*Pistia stratiotes*	Water lettuce	Floating
Ceratophyllaceae	*Ceratophyllum demersum*	Hornwort	Submerged
Convolvulaceae	*Ipomoea aquatic*	Water spinach,	Emergent
	Ipomoea asarifolia	Ginger leaf	Emergent
Cyperaceae	*Carex autro-africana*	Cat's tail sedge	Emergent
	Cyperus dives	Giant sedge	Emergent
	Rynchospora corymbosa		Emergent
	Scirpus articulates		Emergent

Fabaceae	*Neptunia oleracea*	Water mimosa	Floating
Hydrocharitaceae	*Najas guadalupensis*	Water nymph	Submerged
Nymphaeaceae	*Nymphaea caerulea*	blue lotus	Floating
	Nymphaea lotus	White lotus	Floating
	Nymphaea nouchalia	Blue lotus	Floating
Onagraceae	*Ludwigia decurrens*	Upright primose	Emergent
	Ludwigia stolonifer	Creeping ludwigia	Floating
Salviniaceae	*Salvinia molesta*	Water varying	Floating
Polygonaceae	*Persicaria senegalensis*		Emergent
	Polygonum senegalense		Emergent
Sphenocleaceae	*Sphenoclea zeylanica*	Wedgewort	Emergent
Poaceae	*Echinochloa pyramidalis*	Antelope grass	Emergent
Poaceae	*Phragmites australis*	Common weed	Emergent
Poaceae	*Andropogon tectrum*	Horse grass	Emergent
Potamogetonaceae	*Potamogeton schweinfurthii*	Pondweed	Submerged

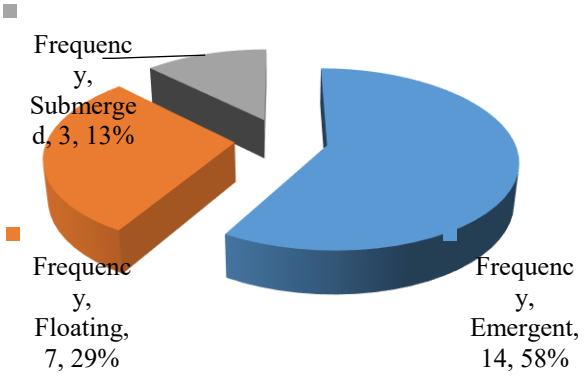

Figure 2: Ecological status of aquatic plants in Ikere-gorge dam, Oyo State, Nigeria

Among the identified species, the floating macrophyte *Salvinia molesta* exhibited the highest abundance across all sampling sites. This species is a known invasive aquatic plant capable of forming dense surface mats that limit oxygen and light penetration, disrupting ecological balance (Richard and Ramey, 2007; BioNET-EAFRINET). Conversely, the submerged species *Najas guadalupensis* had the lowest relative density (0.27). Its delicate structure makes it susceptible to physical disturbance by fish and water currents, limiting its abundance. Spatial analysis of plant abundance across the four sampling sites revealed site-specific dominance patterns (Table 2). In Site A, dominant species included *Potamogeton schweinfurthii*, *Andropogon tectorum*, *Phragmites australis*, and *Echinochloa pyramidalis*. Site B was characterised by *Echinochloa pyramidalis*, *Phragmites australis*, *Andropogon tectorum*, and *Ludwigia stolonifera*, while in Site C, *Echinochloa pyramidalis*, *Ludwigia stolonifera*, *Scirpus articulatus*, and *Cyperus dives* were most abundant. Site D showed dominance of *Echinochloa pyramidalis*, *Ludwigia stolonifera*, *Cyperus dives*, and *Andropogon tectorum*. Frequency of occurrence (Table 2) also varied among species. *Neptunia oleracea* occurred in 50% of the sampled sites, while *Ipomoea aquatica*, *Ceratophyllum demersum*, *Carex autro-africana*, *Persicaria senegalensis*, *Sphenoclea zeylanica*, and *Najas guadalupensis* had a 75% occurrence rate. All other species were found in 100% of the sampling locations, indicating widespread distribution across the Ikere-Gorge dam.

Table 2: Spatial abundance of aquatic plants of Ikere-gorge dam, Oyo State, Nigeria

Plant Species	Site A	Site B	Site C	Site D	Ikere	RD (%)	FO (%)
Salvinia molesta	1020	960	1430	1370	4780	14.15	100
Echinochloa pyramidalis	1120	860	960	1060	4000	11.84	100

Scirpus articulates	680	620	720	580	2600	7.70	100
Phragmites australis	730	860	520	490	2600	7.70	100
Ludwigia stolonifer	510	680	760	640	2590	7.67	100
Andropogon tectrum	380	820	650	610	2460	7.28	100
Cyperus dives	560	510	720	630	2420	7.16	100
Pistia stratiotes	380	470	490	510	1850	5.48	100
Potamogeton schweinfurthii	330	460	520	420	1730	5.12	100
Rynchospora corymbosa	440	340	470	390	1640	4.85	100
Nymphaea nouchalia	310	290	420	380	1400	4.14	100
Nymphaea lotus	310	350	380	320	1360	4.03	100
Nymphaea caerulea	330	280	250	290	1150	3.40	100
Polygonum senegalense	150	120	210	170	650	1.92	100
Ludwigia decurrens	110	140	160	210	620	1.84	100
Ipomoea asarifolia	110	100	140	50	400	1.18	100
Ipomoea aquatic	130	80	160	0	370	1.10	75
Ceratophyllum demersum	150	110	0	80	340	1.01	75
Carex autro-africana	130	0	50	80	260	0.77	75
Persicaria senegalensis	0	50	90	70	210	0.62	75
Sphenoclea zeylanica	50	0	30	70	150	0.44	75
Neptunia oleracea	0	0	40	70	110	0.33	50
Najas guadalupensis	10	30	50	0	90	0.27	75
Total	7940	8130	9220	8490	33780	100.00	

RD: Relative Density; FO: Frequency of Occurrence

Biodiversity assessment (Table 3) revealed a gamma diversity (γ) of 23 species, with proportional diversity of 0.10 and differentiation diversity of 0.91. Alpha diversity across sites ranged from 20 to 22 species: Site A (21), Site B (20), Site C (22), and Site D (21). These figures reflect moderate to high site-level species richness. Additional diversity metrics are presented in Table 4. Dominance index remained constant across all sites at 0.08, indicating low dominance and even species distribution. The Simpson index was 0.92 across all sites. In contrast, the Shannon-Wiener index ranged from 2.71 (Site B) to 2.75 (Sites A and C), suggesting moderate species diversity in line with Dienye (2015) and Ghosh and Biswas (2015), who reported Shannon index values in similar ranges. Evenness values ranged from 0.71 to 0.75, indicating a relatively balanced community structure.

Table 3: Diversity indices of aquatic plants of Ikere-gorge dam, Oyo State, Nigeria

	Site A	Site B	Site C	Site D	Ikere
Individuals	7940	8130	9220	8490	33780
Taxa_S	21	20	22	21	23
Dominance_D	0.08	0.08	0.08	0.08	0.08
Simpson_1-D	0.92	0.92	0.92	0.92	0.92
Shannon_H	2.75	2.71	2.75	2.72	2.76
Evenness_e^H/S	0.74	0.75	0.71	0.73	0.69

The predominance of Cyperaceae, an emergent plant family, is consistent with findings by Dienye and Olopade (2017) and Dienye (2015), who reported high species representation of this family in Oyan Lake and New Calabar River, respectively. According to Reznicek (2013), Cyperaceae species are highly adaptable, occupying diverse aquatic and semi-aquatic habitats except extreme environments like Antarctica. Their ecological roles are multifaceted: nutrient uptake (especially phosphorus and nitrogen), primary productivity, habitat provision for aquatic fauna, and erosion control. Mishra *et al*. (2016) and Encyclopaedia Britannica (2013) also noted their ethnobotanical significance, including use in weaving, traditional medicine, and as food sources for wildlife.

The high prevalence of *Salvinia molesta* may be linked to its invasive nature and rapid vegetative growth. Its dominance threatens aquatic biodiversity by obstructing sunlight, lowering dissolved oxygen levels, and limiting habitat availability for submerged species and fish (Richard and Ramey, 2007). On the other hand, submerged plants, despite being the least represented group in this study (13%), play crucial ecological roles. As Yamaki and Yamamuro (2013) noted, submerged plants like *Najas guadalupensis* provide refuge from predators, serve as foraging grounds, and contribute to water quality by trapping sediments and absorbing nutrients. Their presence in deeper zones away from the littoral region further enhances habitat heterogeneity (Valley *et al*., 2004).

Emergent species such as *Echinochloa pyramidalis* and *Phragmites australis*, which were among the most abundant across sites, are indicative of siltation and nutrient enrichment in the littoral zones, as observed by Ghosh and Biswas (2015). Their dominance supports the notion of ecosystem transition influenced by anthropogenic inputs. Several floating plants identified in this study, *Pistia stratiotes* (water lettuce) and *Ipomoea aquatica* (water spinach), have been similarly documented by Okayi *et al*. (2013). These plants contribute to ecosystem aesthetics and contribute to nutrient recycling and water purification.

The moderate Shannon-Wiener diversity index values (2.71–2.75) reflect a balanced community structure and align with the findings of Dienye (2015), who reported a value of 2.72 in the New Calabar River. Ghosh and Biswas (2015) suggest that Shannon values between 2 and 3 indicate moderately diverse aquatic ecosystems, while values above 3 suggest high diversity. Furthermore, the dominance index (0.08) and Simpson index (0.92) obtained in this study support the conclusion that no single species overly dominates the plant community in Ikere-Gorge, indicating stable ecological dynamics.

In addition to their ecological roles, some aquatic plants, such as *Nymphaea spp.,* are recognised for their edibility and use in traditional diets. Narasimha and Benarjee (2016) highlighted the significance of aquatic plants as food sources for both humans and wildlife. Okayi *et al.* (2013) also emphasised their value in fish nutrition, waterfowl habitat, and ethnobotanical applications. The aquatic plant community in Ikere-Gorge dam exhibits moderate diversity with dominance by emergent macrophytes, particularly from the Cyperaceae and Poaceae families. The presence of invasive species like *Salvinia molesta* and the limited distribution of submerged plants such as *Najas guadalupensis* warrant ecological monitoring and management to maintain ecosystem balance and biodiversity conservation.

Conclusion

This study comprehensively assesses aquatic macrophyte diversity in Ikere-

Gorge, highlighting the richness, composition, and ecological distribution of plant species across four sampling sites. The dominance of emergent vegetation, particularly from the Cyperaceae and Poaceae families, indicates progressive shoreline colonisation likely driven by siltation and nutrient accumulation. The widespread occurrence of invasive species such as *Salvinia molesta* poses a potential threat to native biodiversity. At the same time, the low abundance of submerged macrophytes like *Najas guadalupensis* reflects possible habitat alteration or competitive exclusion. The moderate species diversity observed across the sites underscores the ecological significance of Ikere-Gorge as a habitat for diverse aquatic flora. These findings serve as a baseline for future monitoring and support the need for integrated management strategies aimed at conserving aquatic plant diversity, controlling invasive species, and sustaining the ecological integrity of the reservoir. Long-term ecological studies, including seasonal monitoring and investigation of anthropogenic pressures, are recommended to deepen our understanding of vegetation dynamics and guide evidence-based conservation efforts within the catchment area.

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SUB-THEME 2: COMBATING DEFORESTATION, PESTS, AND ILLEGAL WILDLIFE TRADE THROUGH ADVANCED TECHNOLOGIES

HERBICIDAL POTENTIALS OF THREE BOTANICALS IN COWPEA FIELD, OYO STATE, NIGERIA

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ABSTRACT

Cowpea is a staple crop in Nigeria, rich in protein, but weeds hinder its production. Synthetic herbicides, while effective, pose environmental and health risks. Bio-herbicides offer a promising alternative, being both practical and eco-friendly. This study investigated the herbicidal potential of three plant extracts: *Eucalyptus torreliana* (ET), *Eucalyptus camaldulensis* (EU), and *Leuceania leucocephala* (LL), in cowpea production, using standard procedures. Concentrations (%) of the botanicals (100%, 75%, 50%, 25%); distilled water (0%) and Paraquat (P) as controls (treatments) were used. 2 mL of each treatment were added to test seed germination (SGT) of cowpea in a petri dish for seven days. The plumule (PL, cm) and radicle (RL, cm) lengths of the crops were measured. The study applied treatments to cowpea plants in pots at two stages (before and 5 weeks after planting) and monitored them for 11 weeks. The effects on plant height (PH), Number of leaves (NL), and grain yield (GY) were measured, as well as the impact on weed growth. The data was analysed using statistical methods to determine significant differences (α=0.05). The phytochemical contents in the EU were higher in total phenols, tannins, and saponins (32.04±0.10, 27.40±0.04, and 20.15±0.03 mg/g, respectively). The SGT of cowpea ranged from 80.0±0.4 to 100.0±0.5 across the treatments. Cowpea had significantly higher PL (16.0±0.7) and RL (11.2±1.2) with 25% LL than other extracts. In the pot experiments, phytotoxic effects on PH of cowpea (47.1±3.2) under Paraquat at 9 WAP were significantly higher, while PH (4.8±0.4) was least under Paraquat for cowpea. Phytotoxic effects of 25% EU on cowpea NL (39.3±4.1) at 9 WAP were significantly higher, while 16.3±2.1 at 50% LL was the least. Significantly higher GY (4.2±0.5) of cowpea was obtained at 50% LL, with the least value (0.1±0.1) at Paraquat. The RIV of *Mitracarpus villosus* (52.5) was higher at 3 WAP under 0%, while the least was 7.34 at 0% EU at 7 WAP. These results suggest that the botanical extracts have potential as eco-friendly bio-herbicides in cowpea production, offering an alternative to synthetic herbicides. The study's findings can contribute to developing sustainable and environmentally friendly weed management practices.

Key words: - Bio-herbicides, *Eucalyptus torreliana, Eucalyptus camaldulensis*, *Leuceania leucocephala,* cowpea

INTRODUCTION

Cowpea is one of the foremost food crops widely produced and consumed in Nigeria due to its high protein content. Their production is constrained by weed interference, diseases and pest infestations (Asiwe, 2007). Weeds are a significant hazard to agricultural systems, causing productivity failure. Modern agricultural practices use chemicals to combat weeds and other pests. But the adverse effect of the agrochemicals on the environment, including food safety and human heath, has prompted urgent need to search for alternative weed management methods (Farooq *et al*., 2013). Plant products with biologically active substances such as terpenoids, tannins, saponins, etc, has potential for weed control in modern agriculture (Khan *et al*., 2011; Araniti *et al*., 2012). It has been shown that *Eucalyptus* species have vigorous allelopathic activity on plants (Gliessman, 2007). They belong to the family Myrtaceae and are indigenous to Australia and are distributed worldwide (McDonald *et al*., 2009). Some species of Eucalyptus include: *E. globulus*, *E.*

grandis, *E. robusta*, *E. torelliana*, *E. camaldulensis.* Extract from *E. camaldulensis* on tomato significantly inhibited growth (Fikreyesus *et al*., 2011). *Leucaenia leucocephala is a* leguminous tree from Mexico and is found throughout the subtropical and tropical regions (Aganga and Tshwenyane, 2003). It has multiple uses, emphasising fixing nitrogen in the soil, reforestation of degraded areas, feed, green manure and allelopathy (Meena *et al*., 2013). Phytotoxic allelochemicals, such as mimosine, have been identified in the species' leaves (John and Narwal, 2003). Therefore, the herbicidal potential of *Eucalyptus torelliana, Eucalyptus camaldulensis and Leucaenia leucocephala* extracts in cowpea production was assessed in Oyo State to evaluate the effects of different concentrations of the plant extracts of *Eucalyptus camudulensis, Eucalyptus torreliana* and *Leucena leucocephala* on seed germination, seedling growth, weed flora and yield of cowpea.

MATERIALS AND METHODS

STUDY AREA

Between 2014 and 2016, this study was carried out at the Ecology Research Laboratory, Rooftop, Bacteriology and Virology Research Laboratory, Toxicology Research Laboratory and the Crop Garden of the Department of Crop Protection and Environmental Biology, University of Ibadan, Ibadan, Nigeria. The Crop Protection and Environmental Biology department lies between Latitude 7° 27' 0" N and 3° 53' 0" E.

SAMPLE COLLECTION AND PREPARATION

Topsoil was collected from the CPEB crop garden, U.I. into a 10kg pot. Homogenised soil sample was air-dried for seven days in the Ecology lab. CPEB and later taken to the Department of Bioscience, FRIN for physico-chemical analysis using standard procedures (AOAC, 2001). Cowpea seeds (Ife brown) were collected from the Institute of Agricultural Research and Training (IAR&T). Botanicals were sourced from FRIN premises and identified in FRIN Herbarium with 111806, 111807 and 111808 for *Eucalyptus torreliana, E. camudulensis* and *Leuceania leucocephala,* respectively. They were air dried for 4 weeks, milled and soaked for 48 hours. The extract was stored in the refrigerator before use.

Phytochemical analysis was carried out on plant species' air-dried leaves using standard procedures at IITA. Petri- dishes experiment was done in CPEB, the phytotoxic effects of ET, EC and LL each by adding 2 mL of 100%, 75%, 50%, 25% for 7 days on cowpea (Ife brown) seed germination were evaluated in Complete Randomized Design (CRD) with three replicates, distilled water served as control (0%). Data on Percentage Seed Germination-PSG (%), Plumule length -PL (cm) and Radicle Length-RL (cm) were assessed.

$$\text{Percentage Germination} = \frac{No\ of\ germinated\ seeds}{Total\ No\ of\ seeds\ plated} \times 100$$

The pot trial were arranged in CRD with three replicates, treatments: 200 mL of 100%, 75%, 50%, 25%, 0% of ET, EC and LL with Paraquat-P (5mL in 1 L/ ha) were applied before and five weeks after sowing (WAS) to examine pre-emergence and post-emergence potentials of the botanicals. At 3, 5, 7, 9 and 11, WAS Plant height-PH (cm) and Grain yield-GY (g/pot) were assessed. Weed flora and their Relative Importance Values (RIV) were also determined using standard procedures (Akobundu *et al.,* 2016).

$$\text{Relative Importance Value (RIV)} = \frac{(Relative\ frequency + Relative\ Density)}{2}$$

Data were analyzed using descriptive statistics and ANOVA$\alpha_{0.05.}$

RESULT

Table 1: Quantitative determination of the phytochemicals in the extracts of *Eucalyptus torelliana, E. camudulensis and L. leucocephala*

	Plant species

Phytochemicals	*Eucalyptus torelliana* (mg/g)	*Eucalyptus camudulensis* (mg/g)	*Leuceania leucocephala* (mg/g)
Alkaloids	2.55±0.07^{c}	4.83±0.04^{b}	11.40±0.15^{a}
Flavonoids	0.29±0.01^{b}	1.42±0.01^{a}	0.17±0.00^{c}
Mimosine	0.27±0.01^{b}	0.34\±0.01^{b}	5.09±0.05^{a}
Saponins	14.18±0.06^{b}	20.15±0.03^{a}	6.30±0.14^{c}
Tannins	17.91±0.09^{b}	27.40±0.04^{a}	8.55±0.19^{c}
Total phenols	21.78±0.08^{b}	32.04±0.10^{a}	9.47±0.08^{c}

Means ± standard errors along a row having the same letter(s) as superscript are not significantly different at 5% probability.

Table 2: Effect of different aqueous plant extracts on percentage seed germination, plumule and radicle length of cowpea *Vigna unguiculata* (L.)

Trt.	Conc. (%)	Ist Trial			2nd Trial		
		PSG	PL (cm)	RL (cm)	% SG	PL (cm)	RL (cm)
ET	100	93.33±0.2^{ab}	3.09±0.4^{d}	1.94±0.1^{e}	93.33±1.0^{ab}	3.36±0.2^{d}	2.14±0.1^{ef}
	75	96.67±0.3^{a}	3.21±0.2^{d}	2.69±0.4^{de}	96.67±0.4^{a}	3.36±0.3^{d}	2.52±0.2^{ef}
	50	96.67±0.3^{a}	4.78±0.4^{cd}	3.4±0.3^{de}	96.67±0.4^{a}	4.3±0.3^{cd}	3.03±0.2^{de}
	25	90.00±0.3^{abc}	9.17±0.6^{b}	5.08±0.8^{bc}	96.67±0.5^{a}	5.44±0.3^{c}	4.49±0.3^{bc}
	0	96.67±0.3^{a}	17.64±2.0^{a}	6.21±0.4^{b}	100.0±1.6^{a}	10.56±0.9^{a}	5.03±0.2^{bc}
EU	100	100.0±0.5^{a}	4.68±0.3^{cd}	2.49±0.2^{de}	83.33±0.4^{b}	2.61±0.3^{d}	1.13±0.1^{f}
	75	93.33±0.4^{ab}	3.68±0.3^{cd}	5.03±0.6^{bc}	93.33±1.0^{a}	3.26±0.4^{d}	1.44±0.1^{f}
	50	96.67±0.2^{a}	5.0±0.3^{cd}	3.26±0.3^{de}	97.78±1.2^{a}	3.58±0.4^{d}	1.46±0.1^{f}
	25	93.33±0.4^{ab}	6.74±0.4^{bc}	5.03±0.3^{bc}	100.0±0.8^{a}	3.47±0.3^{d}	1.82±0.2^{ef}
	0	96.67±0.3^{a}	17.64±2.0^{a}	6.21±0.4^{b}	100.0±1.6^{a}	10.56±0.9^{a}	5.03±0.2^{bc}
LL	100	96.67±0.3^{a}	3.67±0.2^{cd}	1.97±0.2e	100.0±1.2^{a}	5.59±0.4c	3.89±0.3^{cd}
	75	83.33±0.6^{bc}	5.73±0.5^{cd}	3.97±0.3^{cd}	98.90±1.4^{a}	4.14±0.2^{cd}	4.80±0.2^{bc}
	50	80.0±0.4^{c}	6.84±0.6^{bc}	3.80±0.4 ^{cd}	96.67±1.2^{ab}	5.53±0.4^{c}	5.91±0.2^{ab}
	25	96.67±0.3^{a}	15.96±0.7^{a}	11.24±1.2^{b}	97.78±1.3^{a}	8.26±0.6^{b}	6.53±0.4^{a}
	0	96.67±0.3^{a}	17.64±2.0^{a}	6.21±0.4b	100.0±1.6^{a}	10.56±0.9^{a}	5.03±0.2^{bc}

ET - Eucalyptus torelliana, EU - Eucalyptus camudulensis, LL - Leucaenia leucocephala , Conc.- concentration, distilled water (0), PSG- % Seed Germination, Plumule length –PL, Radicle Length-RL

Means ± standard errors within a column followed by the same letter(s) are not significantly different at 5 5% probability level DMRT.

Table 3: Phytotoxic effect of different aqueous botanical extracts and Paraquat on plant height and grain yield of *Vigna unguiculata* (Cowpea)

	First trail				Second trail		
Trt	Conc. (%)	5 WAP PH (cm)	9 WAP PH (cm)	Grain yield (g)	5 WAP PH (cm)	9 WAP PH (cm)	Grain yield (g)
P		22.53±2.5^{ab}	42.09±4.1^{bc}	0.37±0.1^{ab}	7.8±0.8^{c}	15.43±1.8^{de}	0.37±0.1^{ab}
ET	100	13.17±2.2^{abc}	18.15±2.0^{cd}	3.07±0.2 ^{a}	11.90±1.5^{bc}	25.80±2.8^{abcd}	3.04±0.2 ^{a}
	75	23.10±2.8^{ab}	35.41±2.8^{cd}	1.00±0.1^{ab}	19.17±2.0^{ab}	34.80±4.2^{abcd}	1.01±0.1^{ab}
	50	19.00±2.4^{abc}	37.67±4.6^{bcd}	1.12±0.1^{ab}	18.07±1.9^{ab}	40.33±5.1^{abc}	1.10±0.1^{ab}
	25	18.60±1.8^{abc}	41.56±3.8^{bcd}	1.7±0.1^{ab}	25.0±2.7^{a}	43.43±4.4^{abc}	1.70±0.2^{ab}
	0	16.73±1.8^{abc}	38.11±4.2^{bcd}	0.97±0.1^{ab}	20.60±3.2^{ab}	41.67±4.5^{abc}	0.97±0.2^{ab}
EU	100	15.27±1.4^{abc}	48.46±3.2^{c}	0.63±0.2^{ab}	25.57±3.0^{a}	46.33±3.8^{a}	0.52±0.1^{ab}
	75	26.20±2.4^{a}	44.58±5.2^{ab}	0.73±0.1^{ab}	19.40±2.0^{ab}	44.20±5.0^{abc}	0.93±0.2^{ab}
	50	26.70±2.2^{a}	40.43±4.2^{a}	0.50±0.1^{ab}	17.13±1.9^{ab}	35.17±4.1^{abcd}	0.50±0.1^{ab}
	25	23.30±2.5^{ab}	36.67±3.2^{abc}	0.37±0.1^{ab}	20.33±1.5^{ab}	20.57±3.6^{bcde}	0.42±0.1^{ab}
	0	16.73±1.8^{abc}	42.00±4.2^{ab}	0.97±0.1^{ab}	20.60±3.2^{ab}	41.67±4.5^{abc}	0.97±0.2^{ab}
LL	100	15.57±1.0^{abc}	39.60±2.8^{a}	0.43±0.2^{ab}	20.77±2.1^{ab}	41.13±3.2^{abc}	0.48±0.1^{ab}
	75	16.77±1.2^{abc}	37.71±2.2^{cd}	0.53±0.2^{ab}	19.67±1.9^{ab}	37.67±3.5^{abcd}	0.43±0.1^{ab}
	50	18.83±1.2^{abc}	39.10±3.2^{a}	3.83±0.4 ^{a}	21.50±2.5^{ab}	42.97±4.0^{abc}	4.23±0.5 ^{a}
	25	20.20±1.8^{abc}	37.0±2.4^{cd}	0.13±0.1^{ab}	19.77±2.0^{ab}	37.67±2.8^{abcd}	0.10±0.1^{ab}
	0	16.73±1.8^{abc}	40.45±3.2^{a}	0.97±0.1 ^{ab}	20.60±3.2^{ab}	41.67±4.5^{abc}	0.97±0.2^{ab}

ET - *Eucalyptus torelliana*, EU - *Eucalyptus camudulensis*, LL - *Leucaenia leucocephala* , *Paraquat* – P, 0%, distilled water, WAP- Weeks After Planting, PH- Plant Height.
Means ± standard errors within a column followed by the same letter(s) are not significantly different at 5 5% probability level DMRT.

DISCUSSION

Our findings showed the presence of phytochemical contents: Tannins, Saponins, mimosine and Total phenols in *Eucalyptus torreliana* (ET), *E. camudulensis* (EU) and *Leuceania leucocephala* (LL), which is in support of Ayepola and Adeniyi (2008). The phytochemical contents in EU were higher in total phenols, tannins and saponins (32.04±0.10, 27.40±0.04 and 20.15±0.03 mg/g, respectively) as in Table 1. The phytotoxic effects of botanical extracts on cowpea seed germination depended on their concentrations; the inhibition was more potent at the higher concentrations, as shown in Plate 1, which is in line with the report of Ataollah *et al* (2014). *Eucalyptus species* extracts inhibited more than *Leuceanian leucocephala, which supports Ayepola and Adeniyi (2008) and* Adeniyi and Ayepola (2008). The Seed Germination of cowpea ranged from 80.0±0.4 to 100.0±0.5 across the treatments (Table 2).

In Table 2, cowpea had significantly higher PL (16.0±0.7) and RL (11.2±1.2) with LL under 25% than other extracts. In the pot experiments as shown in Table 3, phytotoxic effect on PH of cowpea (48.5±3.2) under 100% EU at 9 WAP were significantly higher, while PH (7.8±0.8) were least at 5 WAP under P for cowpea. Significantly higher GY (4.2±0.5) of cowpea was obtained at 50% LL, followed by 100% ET (3.0±0.2), with the least value (0.1±0.1) at Paraquat.

In Table 5, the Relative Importance Value of *Mitracarpus villosus* (52.3) was higher at 3 WAP under 100%, but reduced to 28.5 (100%

Ec at 9-WAP). Concentrations of *Eucalyptus torelliana* at 100% and *Leuceania leucocephala* at 50% enhanced the grain yield of cowpea. Herbicidal effect of *Eucalyptus torelliana* at 50 to 100% concentrations reduced the Relative Importance Value of *Mitracarpus villosus* at 9 WAP.

Table 4: Species composition and Relative Importance Value (RIV) of Weeds at 3 Weeks after planting

Species		First trial						Second trial					
	Family	CM	10%	75%	50%	25%	0%	CM	100%	75%	50%	25%	0%
Ageratum conyzoides Linn.	Asteraceae	-	-	-	-	-	-	-	-	-	3.74	12.31	-
Alternanthera brasilliana (L.) Kuntze	Amaranthaceae	-	-	-	-	-	-	-	-	4.72	4.14	-	3.76
Amaranthus spinosus Linn.	Amaranthaceae	9.33	11.45	5.66	18.77	13.40	10.71	-	-	-	-	-	-
Aspilia africana (Pers.) C.D. Adams	Asteraceae	-	-	-	-	-	-	-	-	-	3.74	-	8.38
Cyperus rotundus Linn.	Cyperaceae	8.67	7.02	5.66	-	-	-	-	-	-	-	-	-
Cyperus esculentus L.	Cyperaceae	-	-	-	-	-	-	-	52.08	44.37	41.05	37.50	32.22
Larpotea austeans (Linn.) chew	Urticaceae	-	-	5.65	4.21	-	-	-	-	-	7.47	-	-
Mariscus alternifolius Vahl	Cyperaceae	8.67	16.63	14.55	21.56	24.16	20.48	-	-	-	-	-	-
Mitracarpus vilosus (Sw) DC.	Rubiaceae	5.00	52.27	36.98	22.47	32.22	35.71	-	-	-	-	-	-
Oldenlandia lancifolia (Schumach.)DC.	Rubiaceae	12.00	19.34	24.75	11.05	20.93	11.91	-	-	-	-	-	-
Oldenlandia corymbosa Linn	Rubiaceae	-	-	-	-	-	-	10.0	13.83	16.03	23.71	20.27	26.67
Phyllantus amarus Schumach. & Thonn.	Phyllanthaceae		-	-	-	-	-	-	26.33	18.54	14.03	14.02	15.13
Syndedralla nodiflora (Linn.)Gaertn.	Compositae	14.00	4.43	6.77	9.30	9.29	14.05	-	-	-	-	-	-
Talinum fruticosum (L) Juss	Talinaceae	-	8.87	-	12.63	-	8.90	-	7.77	16.35	4.14	15.91	9.23
Ageratum conyzoides L.	Asteraceae	-	-	-	-	-	-	-	6.82	14.93	-	18.04	-

Alternanthera brasilliana (L.) Kuntze	Amaranthaceae	-	-	-	-	-	-	-	-	6.94	8.87	-	-
Amaranthus spinosus Linn.	Amaranthaceae	9.33	9.97	9.95	7.49	5.43	10.71	-	-	-	-	-	-
Aspilia africana (Pers.) C.D. Adams	Asteraceae	-	-	-	-	-	-	-	5.49	5.97	8.87	-	-
Cyperus rotundus Linn.	Cyperaceae	8.6	4.52	17.36	-	-	-	-	-	-	-	-	-
Cyperus esculentus L.	Cyperaceae	-	-	-	-	-	-	-	40.38	39.05	39.78	41.21	32.22
Larpotea austeans (Linn.) chew	Urticaceae	-	4.52	-	5.53	4.64	-	-	5.05	5.97	-	4.25	-
Mariscus alternifolius Vahl	Cyperaceae	8.67	13.01	-	22.82	26.62	20.48	-	-	-	-	-	-
Mitracarpus vilosus (Sw) DC.	Rubiaceae	5.0	27.70	35.42	38.15	34.55	35.71	-	-	-	-	-	-
Oldenlandia lancifolia (Schumach.)DC.	Rubiaceae	12.00	25.81	39.27	7.49	14.84	11.91	-	-	-	-	-	-
Oldenlandia corymbosa Linn.	Rubiaceae		-	-	-	-	-	10.0	25.33	9.85	19.46	18.67	26.67
Phyllantus amarus Schumach. & Thonn.	Phyllanthaceae	-	-	-	-	-	-	-	16.93	13.33	11.22	9.32	15.13
Setaria barbata (Lam.) Kunth	Poaceae	-	-	-	-	4.64	-	-	-	-	-	-	-
Syndedralla nodiflora (Linn.)Gaertn.	Compositae	14.0	14.49	-	6.51	9.28	14.05	-	-	-	-	-	-
Talinum fruticosum (L) Juss	Talinaceae	-	-	-	12.03	-	8.90	-	-	3.96	11.81	8.51	9.23
Ageratum conyzoides Linn.	Asteraceae	-	-	-	-	-	-	-	-	-	5.51	8.28	-
Alternanthera brasilliana (L.) Kuntze	Amaranthaceae	-	-	-	-	-	-	-	3.26	4.03	3.70	6.92	-
Amaranthus spinosus Linn.	Amaranthaceae	9.33	15.09	15.54	13.60	4.17	10.71	-	3.26	-	-	-	-

Aspilia Africana (Pers.) C.D. Adams	Asteraceae	-	-	-	-	-	-	-	-	9.44	3.70	-	8.38
Cyperus esculentus L.	Cyperaceae	-	-	-	-	-	-	-	34.78	23.80	30.29	30.10	32.22
Cyperus rotundus Linn.	Cyperaceae	8.67	4.55	-	16.23	16.85	-	-	-	-	-	-	-
Larpotea austeans (Linn.) chew	Urticaceae	-	-	-	5.25	-	-	-	6.52	-	-	6.92	-
Mariscus alternifolius Vahl	Cyperaceae	8.67	29.09	7.69	-	22.46	20.48	-	-	-	-	-	-
Mitracarpus vilosus (Sw) DC.	Rubiaceae	5.0	29.09	27.69	42.99	42.94	35.71	-	-	-	-	-	-
Oldenlandia corymbosa Linn.	Rubiaceae	-	-	-	-	-	-	10.0 .	12.29	23.56	27.75	26.70	26.67
Oldenlandia lancifolia (Schumach.) DC.	Rubiaceae	12.0	4.55	23.54	13.60	4.17	11.91	-	-	-	-	-	-
Phyllantus amarus Schumach. & Thonn.	Phyllanthaceae	-	-	-	-	-	-	-	12.18	6.78	9.57	7.26	15.13
Syndedralla nodiflora (Linn.) Gaertn	Compositae	14.0	6.55	13.54	-	4.17	14.05	-	-	-	-	-	-
Talinum fruticosum (L) Juss	Talinaceae	-	6.55	-	-	-	8.90	-	11.22	14.94	9.57	10.71	9.23

CM – Paraquat, Et - Eucalyptus torelliana, Ec - Eucalyptus camudulensis, Ll - Leucaenia leucocephala; Dw (0) – distilled water

Table 5: Species composition and Relative Importance value of weeds in cowpea at 9 Weeks after planting cowpea seed

Trt	Species	Family	First trial						Second trial					
			CM	100%	75%	50%	25%	0%	CM	100%	75%	50%	25%	0%
Ec	*Ageratum conyzoides* L.	Asteraceae	-	-	-	-	-	-	16.12	7.05	7.55	12.93	24.44	5.11
	Alternanthera brasilliana (L.) Kuntze	Amaranthaceae	-	23.57	21.64	22.29	21.75	-	-	38.64	-	-	-	7.22
	Amaranthus spinosus Linn.	Amaranthaceae	-	5.72	10.03	10.83	8.60	-	-	-	-	-	-	-
	Aspilia africana (Pers.) C.D. Adams	Asteraceae	-	-	-	-	-	-	10.17	-	4.77	-	-	9.72
	Cyperus esculentus L.	Cyperaceae	-	-	-	-	-	-	-	8.30	30.06	15.87	22.48	16.39
	Cyperus rotundus Linn.	Cyperaceae	5.60	7.14	11.91	4.38	14.70	10.27	-	-	-	-	-	-
	Larpotea austeans (Linn.) chew	Urticaceae	-	-	5.01	-	3.39	8.44	-	-	-	-	-	-
	Mariscus alternifolius Vahl	Cyperaceae	8.46	-	-	-	-	21.02	14.40	38.64	16.95	11.52	7.49	20.50
	Mimosa pudica L.	Fabaceae	-	-	-	-	-	-	-	-	7.55	-	-	-
	Mitracarpus vilosus (Sw) DC.	Rubiaceae	5.60	28.5	-	-	-	6.90	-	-	-	-	-	-
	Oldenlandia corymbosa Linn.	Rubiaceae	-	-	-	-	-		16.12	8.30	9.40	21.50	14.99	87.50
	Phyllantus amarus Schumach. & Thonn.	Phyllanthaceae	-	-	-	-	-	4.20		22.39	18.02	10.81	13.03	9.72
	Shrankia leptocarpa DC.	Fabaceae	-	-	-	-	-	-	14.40	7.05	5.70	9.40	12.05	16.67
	Syndedralla nodiflora (Linn.)Gaertn.	Compositae	11.19	-	-	-	-	18.90	-	-	-	-	-	-
	Talinum fruticosum (L) Juss	Talinaceae	12.62	33.58	30.14	29.79	24.80	10.65	-	8.30	-	5.76	5.53	4.44

	Tithonia diversifolia (Hemsl.) A. Gray.	Asteraceae		4.29	8.138	13.13	3.40			-	-	-	-	-
Et	*Ageratum conyzoides* Linn.	Asteraceae	-	-	-	-	-	-	16.12	-	-	-	-	5.11
	Aspilia Africana (Pers.) C.D. Adams	Asteraceae	-	-	-	-	-	-	10.17	-	-	-	-	9.72
	Alternanthera brasilliana (L.) Kuntze	Amaranthaceae	-	-	-	-	-	-	-	-	5.83	7.59	-	7.22
	Cyperus esculentus L.	Cyperaceae	-	-	-	-	-	-	-	28.85	11.65	16.12	19.60	16.39
	Cyperus rotundus Linn.	Cyperaceae	5.60	-	-	-	-	-	10.27	-	-	-	-	-
	Larpotea austeans (Linn.) chew	Urticaceae	-	-	-	-	-	8.44	-	-	-	-	-	-
	Mariscus alternifolius Vahl	Cyperaceae	8.46	-	-	-	-	21.02	14.40	-	-	-	-	20.50
	Mitracarpus vilosus (Sw) DC.	Rubiaceae	5.60	28.53	28.76	42.52	34.15	6.90	-	-	-	-	-	-
	Oldenlandia corymbosa Linn.	Rubiaceae	-	-	-	-	-	-	16.12	-	-	-	-	87.50
	Oldenlandia lancifolia (Schumach.)DC.	Rubiaceae	-	10.47	19.83	14.05	16.18	33.15	33.15	-	-	-	-	-
	Phyllantus amarus Schumach. & Thonn.	Phyllanthaceae	-	-	-	-	-	4.20	-	12.50	18.44	5.09	-	9.72
	Shrankia leptocarpa DC.	Fabaceae	-	-	-	-	-	-	14.40	-	-	-	-	16.67
	Syndedralla nodiflora (Linn.)Gaertn.	Compositae	11.19	-	-	-	-	18.90	-	-	-	-	-	-
	Talinum fruticosum (L) Juss	Talinaceae	12.62	-	-	-	-	10.65	-	-	-	-	-	4.44
Ll	*Ageratum conyzoides* L.	Asteraceae	-	-	-	-	-	-	16.12	11.68	16.67	19.90	13.66	5.11

Alternanthera brasilliana (L.) Kuntze	Amaranthaceae	-	-	-	-	-			-	-	4.00	10.42	7.22
Amaranthus spinosus Linn.	Amaranthaceae	-	13.21	10.51	-	6.19	-	-	-	-	-	4.05	-
Aspilia africana (Pers.) C.D. Adams	Asteraceae	-	-	-	-	-	-	10.17	-	-	-	-	9.72
Cyperus esculentus L.	Cyperaceae		-	4.30	-	-	-	-	19.56	12.22	18.15	20.49	-
Cyperus rotundus Linn.	Cyperaceae	5.60	-	-	-	-	10.27	-	-	-	-	-	-
Larpotea austeans (Linn.) chew	Urticaceae	-	-	-	10.47	3.13	8.44	-	-	-	-	-	-
Mariscus alternifolius Vahl	Cyperaceae	8.46	27.31	18.21	26.79	27.57	21.02	14.40	6.86	26.67	11.51	14.58	20.50
Mitracarpus vilosus (Sw) DC.	Rubiaceae	5.60	29.23	28.27	19.64	41.51	6.90	-	-	-	-	-	-
Oldenlandia corymbosa Linn.	Rubiaceae	-	-	-	-	-	-	16.12	-	4.44	26.04	17.36	87.50
Oldenlandia lancifolia (Schumach.)DC.	Rubiaceae	-	11.03	21.54	53.58	19.37	6.90	-	-	-	-	-	-
Phyllantus amarus Schumach. & Thonn.	Phyllanthaceae	-	-	-	-	-	4.20	-	14.46	12.22	4.88	4.98	9.72
Shrankia leptocarpa DC.	Fabaceae	-	-	-	-	-	-	14.40	4.82	10.00	9.76	15.86	16.67
Syndedralla nodiflora (Linn.)Gaertn.	Compositae	11.19	7.95	12.89	-	-	18.90	-	-	-	-	-	-
Talinum fruticosum (L) Juss	Talinaceae	12.62	7.95	-	-	5.37	10.65	-	9.64	12.22	5.76	4.98	4.44

Trt. – Treatment, CM – Paraquat, Et - Eucalyptus torelliana, Ec - Eucalyptus camudulensis, Ll - Leucaenia leucocephala; Dw (0) – distilled water, - NIL

CONCLUSION

This present study was designed to assess the herbicidal potential of *Eucalyptus torelliana, Eucalyptus camaldulensis and Leucaenia leucocephala* extracts in a cowpea field. Our results have shown that the botanicals used are capable of inhibiting the weed and enhancing the grain yield. Our research, therefore, has thrown up many questions that need further investigation. Further work needs to be done to establish whether botanical extracts can be an effective bio-herbicide in crop production in both small and large-scale farming to enhance environmental sustainability and food safety.

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INVESTIGATION OF IN-VITRO ANTIBACTERIAL ACTIVITY OF THREE FOREST PRODUCTS.

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ABSTRACT

This study investigated the aqueous extract of *Fluerya aestuans*, *Ocimum basilicum* and *Acalypha wilkesiana* for in vitro antimicrobial activities by agar diffusion and tube dilution techniques. The extract except *Fluerya aestuans* inhibited the growth of standard and local strains of bacteria, including *Pseudomonas aeruginosa, Staphylococcus aureus, Escherichia coli, and Klebsiella pneumoniae.*

The aqueous extracts of these plants did not exert any inhibitory action on *Candida albicans*. The minimum inhibitory concentrations of the extracts ranged between 8mg/ml and 64mg/ml, while the minimum bacteriocidal concentrations were between 32mg/ml and 64mg/ml.

Keywords: *Acalypha wilkesiana, Fluerya aestuans, Ocimum basilicum, Pseudomonas aeruginosa, Staphylococcus aureus, Escherichia coli, Klebsiella pneumoniae, Candida albicans, ciprofloxacin, ketoconazole.*

INTRODUCTION

Medicinal plants are widely used in different parts of Nigeria. The popularity of traditional medicine is peculiar to the community belief that certain types of diseases can only be cured by traditional medicine (Bannerman et al, 1975). Sofowora (1984) reported that medicinal plants contain some therapeutic agents with antimicrobial activity. Problems of resistance with orthodox drugs, cost, and poor socio-economic status of rural dwellers informed this group to undertake this study.

Therefore, the present study used three medicinal plants (Acalypha wilkesiana; Fluerya aestuans, Ocimum basilicum) to treat ailments of possible bacterial or fungal origin, such as oral thrush in children. The plants were collected in Lagos, southwestern Nigeria. They were studied for their antibacterial activity. It is hoped that this study will lead to the discovery of new compounds that could be used to formulate new and more potent antibacterial drugs that might overcome the problem of resistance to the currently available antibacterial drugs.

MATERIALS AND METHODS

Extraction procedure

Fresh leaves of *Acalypha wilkesiana, Ocimum basilicum,* and *Fluerya aestuans* were obtained from the Nigerian Natural Medicine Development Agency, Lagos, Nigeria.

The leaves were air-dried at ambient temperature for 1 week. They were blended into fine powder and kept in a transparent desiccator.

100grams of each powder material was soaked in sterile distilled water. Each mixture was stirred for several hours using a sterile glass rod and refrigerated before usage.

The mixture was sieved with muslin cloth and centrifuged at 700rpm for 30 minutes to remove the suspension. The supernatant was collected and filtered using a Whatman paper No. 1 filter.

A greenish filtrate was obtained for all plants except *A. wilkesiana,* which was yellowish. The filtrate was freeze-dried using the Edward freeze-drying machine.

The final extract was sticky brown *for A. wilkesiana,* brisk or sand-like for *Fluerya aestuans* and crispy, shining for *O. basilicum.*

Each extract was weighed and stored in universal bottles and kept in a refrigerator at 4^{0} ˚C before testing.

The total yields of A, B, and C were 6.1, 6.0 and 6.3, respectively.

Microbes used in this study were *Pseudomonas aeruginosa, Staphylococcus aureus, Escherichia coli, Klebsiella pneumoniae*, and *Candida albicans* obtained orally from children in Lagos metropolis. (Gbaja Health Centre and Mosan Healthcare in Surulere and Ipaja local government areas, respectively, in the state).

Sixty samples were collected with cotton wool swabs from the throats and mouths of the children aged between 6 months and 24 months, 34 of them were female, while 26 were male.

The samples were maintained in the transparent media slants at 4^{0} ˚C before use. The four strains of bacteria and fungi were identified and authenticated by Dr. T. Niemogha of the Microbiology Dept, University of Lagos, Lagos.

Antimicrobial Assay/Screening

1.28 grams of the dry extract was weighed and reconstituted using 10m/s sterile distilled water to give a 128mg/ml concentration.

The test organisms were cultured overnight at 37^{0}C. The broth cultures were centrifuged, and the supernatant was removed. The cells were washed 3 times using Phosphate Buffer Saline (PBS). The cell suspension was made using sterile PBS in a transparent tube and compared with Macfalan standard No. 0.5, and this was diluted with an inoculum of 1 x 10 c.f.u.

The inoculum was seeded on nutrient agar plates. The seeded agar plate was perforated using a cork borer, filled with the reconstituted plant extract, and incubated for 24 hours. Another set of plates was seeded, and the control antibiotic disc (ciprofloxacin 5µg) was placed in each plate seeded with bacteria, while ketoconazole (130uµg) was placed in the plates seeded with fungus; both were incubated appropriately as in the work of Irobi et al, (1991).

DETERMINATION OF MINIMUM INHIBITORY CONCENTRATION (MIC).

MIC: the lowest concentration of the extract that will not permit any visible growth of the bacteria and fungi. The stock was filled and sterilised using a membrane filter with 0.22 micropores (µ), and 128 mg/ml was double serially diluted in nutrient broth, giving various concentrations ranging from 64 mg/ml to 1mg/ml.

The various dilutions were inoculated with a loopful of standardised inoculum and incubated at 37 ^{0}C °C for 24 hours, after which the tubes were observed to see turbidity or growth. The tube not showing any visible turbidity (the least dilution) was taken as MIC.

DETERMINATION OF MINIMUM BACTERIOCIDAL CONCENTRATION

MBC: The lowest extract concentration that did not yield a single bacterial colony on the solid agar after 24 24-hour incubation period. It was after mining by taking samples from the tubes used in the MIC assay (which showed no visible growth after 24 hours) and diluting with normal saline in the ratio 1:4.

50ul of this was sub-cultured into a freshly prepared mackonkey agar and incubated overnight. After 24 hours, the tube showed no growth (that is, the least concentration on the solid agar was taken as MBC) as in the work of Ilori et al, (1991).

RESULTS

After 24 hours, the plates were observed to see

and measure clear zones of inhibition around the well containing the extract.

The inhibition zone diameter for the antibiotic control was measured. Microorganisms in agar plates (growth media) were used as the positive control.

A total of 5 strains of microorganisms (4 bacteria and I fungus) were used, including gram-positive and gram-negative bacteria. After the incubation of the inoculated plates with the various microorganisms for 24 hours, there were visible zones of growth inhibition observed with *A. wilkinesia* and *O. basilicum* for *E. coli, S. aureus, P. aeruginosa, K. pneumoniae,* but no visible zone of inhibition for *C. albicans* by the two plants, while no visible zone of growth inhibition was observed for *F. aestuans* for all the microorganisms. The mean zone of inhibition produced by ciproflaxin for the positive antibacterial control was 31.25mm, while Ketoconazole was 16mm. The vehicle control did not inhibit any of the microorganisms.

ACUTE TOXICITY TESTING.

The test was carried out with the 3 plant extracts because they are all. The oral route was initially used; at 10g/kg, none of the mice died, so the the intraperitoneal route was used.

It is assumed that the plant materials were relatively non-toxic because the toxicity was not up to 10g/kg.

N.B

Water alone was used as a vehicle control, and the result was negligible. Therefore, the effects noticed were strictly due to the medicinal plant extract taken orally in our community.

TABLE OF RESULTS.

TABLE 1- Shows susceptibility of the test organisms to the fresh aqueous extracts of the three selected local medicinal plants, neat (100% concentration): mean diameter of inhibition zones (mm).
A. wilkinesia = Acalypha wilkenesia
O. basilicum = Occimum basilicum
F. aestuans = Fluerva Aestuans
E. coli = Escherichia coli

EXTRACTS		***TEST***	***ORGANISMS***		
		,			
	E. coli	*S. aureus*	*P. aeruginosa*	*K. pneumoniae*	*C. albicans*
A. wilkenesia	*12*	*22*	*12*	*11*	-
O. basilicum	*10*	*11*	*10*	*11*	-
			I		
F. aestuans	-	-	-	-	-

S. aureus = Staphylococcus aureus
P. aerigenosa = Pseudomonas aerigenosa
K. pneumoniae = Klesbiella pneumoniae
C. albicans = Candida albicans

{-} = No inhibition
Diameter of well = 8mm

TABLE 2a - Showing the MIC and MBC of acalypha extract

ACALYPHA EXTRACTS.

Microbes	64	32	16	8	4	2	1	MIC	MBC
E. coli	N	N	G	G	G	G	G	32	64
P. aeruqenosa	N	N	N	N	G	G	G	8	64
S. aureus	N	N	N	G	G	G	G	64	32
K. pneumonia	N	N	G	G	G	G	G	32	64
C. albicans	G	G	G	G	G	G	G	-	-

TABLE 2b - Showing the MIC and MBC of BASILICUM EXTRACT.

Microbes	64	32	16	8	4	2	1	MIC	MBC
E. coli	N	N	G	G	G	G	G	32	64
P. aurugenosa	N	N	G	G	G	G	G	32	64
S. aureus	N	N	G	G	G	G	G	32	64
K. pneumonia	N	N	G	G	G	G	G	32	64
C. albicans	G	G	G	G	G	G	G	-	-

TABLE 3 - SHOWING MINIMUM INHIBITORY CONCENTRATION FOR CIPROFLOXACIN

DRUG	ORGANISMS	MINIMUM INHIBITORY CONCENTRATION
CIPROFLOXACIN	*E. coli*	28mm
	P. aerugenosa	30mm
	S. aureus	34mm
	K. pneumoniae	33mm
KETOCONAZOLE	*C. albicans*	16mm

A PERIOD OF 24 HOURS (ROUTE - PARENTERAL)

DOSE (g/kg)	LOG OF DOSE	PERCENTAGE DEATH	PROBIT OF %DEATH
1.0	0	0%	2.1870
1.2	0.0792	20%	4.1584
1.4 .	O. 1461	60%	5.2533
1.8	0.2553	80%	5.8416
2.0	0.3010	100%	6.6449
Control=sterile water	-	0	2.1870

DETERMINATION OF LD50 OF *O. basilicum, F. aestuans and A. wilkesiana*

DISCUSSION AND CONCLUSION

Forest products continue to be a rich source for therapeutic agents, and this study reveals the potential values of the selected plants.

In the present study, three commonly prescribed medicinal plants were tested for the antimicrobial activity against *S. aureus, E. coli* and *C. albicans.* The results were encouraging as two plants (*A. wilkenesia* and *O. basilicum*) appeared to contain substances that had antimicrobial properties against all the microorganisms used except *C. albicans* (Adesina et al 1980; Olukoya et al 1985).

It is interesting to note the correlation between the claims of the traditional healers and the demonstrated antimicrobial activity. Some of the extracts also exhibited inhibitory activity on organisms not conventionally implicated in diseases.

Two of the screen plants exhibited clear inhibition zones around the wells (Pg 1,3). The two were active against both gram-negative (*E. coli, P. aungenosa, K. pneumoniae*) and gram-positive (*S. aureus*), although acalypha extract has greater activity than *O. basilicum* and *S. aureus*; both plants can be assumed to have a broad spectrum of activities as supported by the works of Alade and Irobi, (1993), Oyelami et ali, (2001), Greyer et al (1996). The inability of the plant *F. aestuans* to inhibit the growth of the microorganisms used in this study contradicts its folklore use for the treatment of oral thrush and sores in children in South-western Nigeria

The minimum inhibitory concentration obtained revealed that ketoconazole is far more potent than the plants used on *Candida albicans*; likewise, ciprofloxacin is more potent on the bacteria than in this study.

The acute toxicity studies revealed that at doses not exceeding 1 g/kg, all the plants used in this study do not produce any lethal effect. However, higher doses between 1.2 - 2.0 g/kg given parenterally produce toxic effects like weakness, discomfort, lesions in the liver (hepatomegaly) and death. The calculated LD50 (Lethal dose for 50% of the population) is 1.48g/kg.

The MIC and MBC results of the plant extract show that the plants have a more bacteriostatic effect than bacteriocidal.

CONCLUSION.

Many investigators have demonstrated the antimicrobial activities of the constituents of forest products (Iwu, 1982), which almost 80% of people in developing countries depend on for primary healthcare needs (WHO, 2023).

It makes it imperative to continue to study and confirm the use of plants and to document the use of medicinal plants in the treatment of infections scientifically, to promote and boost the use of local medicinal plants in modern therapy against diseases caused by microorganisms in man and animal.

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DEFORESTATION CAUSES, EFFECTS, AND CONTROL STRATEGIES IN TSANYAWA LOCAL GOVERNMENT AREA, KANO STATE.

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Abstract

This study investigates deforestation's causes, impacts, and control strategies in Tsanyawa Local Government Area, Kano State, Nigeria, an area located in the Sudan-Sahel ecological zone and increasingly vulnerable to forest degradation. Using a mixed-methods approach, data were collected through structured questionnaires administered to 104 respondents across five wards: Zarogi, Kabagiwa, Tsanyawa, Gozaki, and Daddarawa. The study revealed that agricultural expansion (38.5%), overgrazing (17.3%), fuelwood collection (16.3%), logging (15.4%), and urbanisation (12.5%) are the major drivers of deforestation in the study. Environmental consequences include soil erosion, biodiversity loss, reduced agricultural productivity, water scarcity, and local climate instability. Social effects, such as increased land conflict (44.2%) and loss of cultural heritage (49%), and economic consequences like declining yields (73.1%) and rising wood costs, were also prominent. Despite some awareness of control initiatives, including reforestation and government policies, only 45.2% of respondents considered them effective due to poor community involvement, inadequate funding, and weak policy enforcement. Notably, 68.3% of the respondents expressed willingness to engage in community-based forest management, favouring solar and gas as alternative energy sources to reduce dependency on fuelwood. The study concludes that integrated, community-led approaches supported by robust policy, sustainable agriculture, alternative energy, and environmental education are essential to reversing deforestation trends in Tsanyawa and similar semi-arid regions. Sustainable agricultural practices, renewable energy promotion, community-based forest management, and policy reforms to enhance deforestation control efforts and promote environmental resilience in Tsanyawa and similar ecological zones.

Keywords

Introduction

Deforestation, the large-scale removal of forest cover for alternative land uses such as agriculture, urbanisation, and industrial development, is one of the most pressing environmental crises globally (FAO, 2021; Chakravarty et al., 2012). It is a major driver of biodiversity loss, climate change, soil degradation, and ecosystem disruption. According to the Food and Agriculture Organisation (FAO), an estimated 10 million hectares of forest are lost annually worldwide, with developing countries like Nigeria facing the most severe consequences due to economic pressures, rapid population growth, and dependence on forest resources (FAO, 2021; Acheampong et al., 2019).

The annual forest loss in Africa reaches 3.9 million hectares, primarily due to agricultural expansion, fuelwood harvesting, and weak policy enforcement (FAO, 2021). Nigeria alone loses about 350,000 to 400,000 hectares annually—one of the highest rates in the world—driven by logging, farming, and energy demands (Global Forest Watch, 2023; Ogundele, 2012). The impacts of deforestation are particularly severe in northern Nigeria, where arid and semi-arid conditions heighten vulnerability to

desertification, erratic rainfall, and livelihood disruption (UNECA, 2020).

Tsanyawa Local Government Area in Kano State exemplifies these challenges. The region, historically dependent on forest resources for agriculture, fuel, and traditional medicine, is experiencing rapid forest loss due to slash-and-burn farming, overgrazing, charcoal production, and illegal logging (Aliyu et al., 2014; Nwobodo et al., 2020). These practices degrade the land, reduce soil fertility, and disrupt hydrological cycles, threatening biodiversity and food security.

2. Materials and Methods

2.1 Study Area

The geographical and climatic description of Tsanyawa Local Government Area, Kano State, Nigeria, aligns with the semi-arid characteristics of the region. The area is located approximately at latitude 12.2964° N and longitude 8.2246° E, covering a land area of around 576 square kilometres. It experiences a seasonal climate typical of the semi-arid Sudan Savannah, with a wet season from May to September, an annual rainfall between 600 mm and 800 mm, and a dry season from October to April. During the dry season, temperatures can rise above 40°C, reflecting the Area's proximity to the Sahel region (Kano Emirate Geographic Background, 2024; ResearchGate, 2021; Journals. Agripreneurship, 2021).

According to the 2006 National Population Census (National Population Commission, 2006), Tsanyawa had approximately 115,000 people. However, with an estimated annual population growth rate of 2.6%, the current population is projected to be around 165,000 to 170,000. This growing population exerts increasing pressure on natural resources, including forests, as the demand for agricultural land, fuelwood, and construction materials rises.

The vegetation of Tsanyawa Local Government Area consists of savanna woodlands characterized by scattered drought-resistant trees such as ***Acacia species*** and ***Balanites aegyptiaca***. However, these natural resources face increasing degradation due to human activities like farming, overgrazing, and deforestation. The Area's sandy and loamy soils, although suitable for subsistence agriculture, are highly susceptible to erosion when vegetation cover is removed, exacerbating land degradation challenges (Kano Emirate Geographic Background, 2024; ResearchGate, 2021; Journals. Agripreneurship, 2021).

The economy is predominantly agrarian, with most residents engaged in crop farming and livestock rearing. Millet, sorghum, and groundnuts are commonly cultivated, while cattle, goats, and sheep are extensively raised. Combined with agricultural expansion and grazing, these activities exert significant pressure on forest resources. Unsustainable practices such as slash-and-burn farming, unregulated logging, and fuelwood collection accelerate deforestation.

Tsanyawa's strategic location in the Sudano-Sahelian region makes it an ideal case study for understanding deforestation in semi-arid environments. By exploring deforestation's socio-economic and environmental dynamics, this research aims to provide actionable insights for sustainable resource management in similar regions across Nigeria.

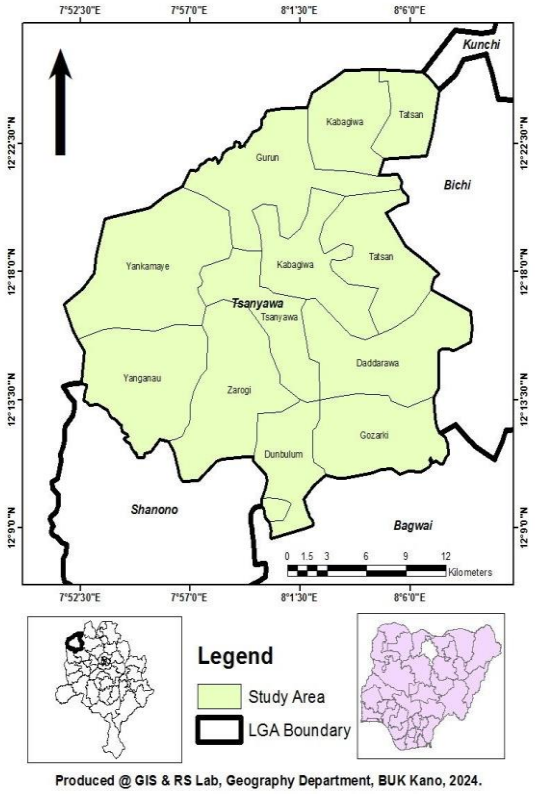


Figure 1: Map of Nigeria showing Tsanyawa Local Government

2.2 Materials Used

The materials required for this study include:

- **Survey Instruments**: Questionnaires and structured interview guides for collecting primary data from residents, farmers, government officials, and environmental groups.
- **Geospatial Tools**: Satellite imagery and Geographic Information System (GIS) software for analyzing forest cover changes.
- **Documentation Sources**: For secondary data collection, academic journals, government reports, and environmental publications.
- **Data Analysis Tools**: Statistical software (e.g., SPSS or Microsoft Excel) for quantitative data analysis and thematic coding tools (e.g., NVivo) for qualitative data.

2.3 Research Design

This study will employ a mixed-method approach, combining qualitative and quantitative research methods to comprehensively understand deforestation in Tsanyawa. The research design is structured as follows:

1. **Qualitative Component**: Conduct in-depth interviews with stakeholders to gather insights into deforestation's socio-economic and environmental drivers.
2. **Quantitative Component**: Use structured surveys to collect numerical data on the extent of deforestation, its impacts, and the effectiveness of control strategies.
3. **Descriptive and Analytical Frameworks**: Employ descriptive statistics to quantify deforestation trends and thematic analysis to interpret qualitative findings.

2.4 Sampling Techniques

The sampling strategy for this study is as follows:

The sampling strategy for this study combines both purposive and stratified random sampling methods to ensure comprehensive representation across the Tsanyawa Local Government Area. The target population includes local farmers, residents, government officials, and environmental organizations. 104 questionnaires were administered across five central wards within the LGA—Zarogi, Kabagiwa, Tsanyawa, Gozaki, and Daddarawa. To ensure broad and balanced representation of the local population, 20 questionnaires were distributed in each of the five wards. An additional four questionnaires were specifically administered in Kabagiwa, bringing the total to 104. This slight increase in Kabagiwa was due to its relatively larger population and a more diverse socio-economic structure, which warranted deeper insight. Purposive sampling was employed to select key informants such as government officials and representatives of environmental organizations, chosen based on their roles and expertise in

forestry management and environmental policies. For local farmers and residents, stratified random sampling was used. This method enabled the categorization of respondents based on socio-economic status, age, gender, and type of farming practice. It ensured that the sample adequately reflects the diversity of experiences and views related to deforestation and its impacts. This mixed-method approach enhances the credibility and representativeness of the data collected, capturing a wide range of perspectives within the study area.

2.5 Data Collection

Data collection involves the use of both primary and secondary sources:

Primary Data: Structured interviews and questionnaires will collect primary data. 100 questionnaires will be distributed among selected individuals across the five wards of Tsanyawa Local Government Area, with 20 respondents per ward. These questionnaires are designed to gather information on residents' reliance on forest resources, awareness of deforestation, and perceptions of control strategies. Additionally, structured interviews will be conducted with key stakeholders, including farmers, local leaders, and forestry officials, to gain deeper insights into the socio-economic dynamics driving deforestation in the Area.

Secondary Data: Secondary data will be obtained from various sources, including government publications, environmental reports, and scholarly articles that detail deforestation trends, causes, and impacts in Nigeria. Historical satellite imagery will also be analyzed to assess changes in forest cover over the past two decades, providing a quantitative perspective on the extent of deforestation in Tsanyawa and offering a broader environmental context for the study.

2.6 Experimental Design (Where Applicable)

While the study does not involve a laboratory experiment, it incorporates the following methodological steps:

1) Identify and map areas of significant deforestation within Tsanyawa using GIS tools.
2) Develop interview and survey protocols to ensure consistency and reliability in data collection.
3) Pilot-test the questionnaires and interview guides to refine their effectiveness before full-scale deployment.

3.0 Results and Discussion

Figure 2: Satellite image showing Tsanyawa LGA as at 2004, where the Area with non-vegetation covering 43km2(8.7%) and Area with vegetation covering 449km2(91.3%)

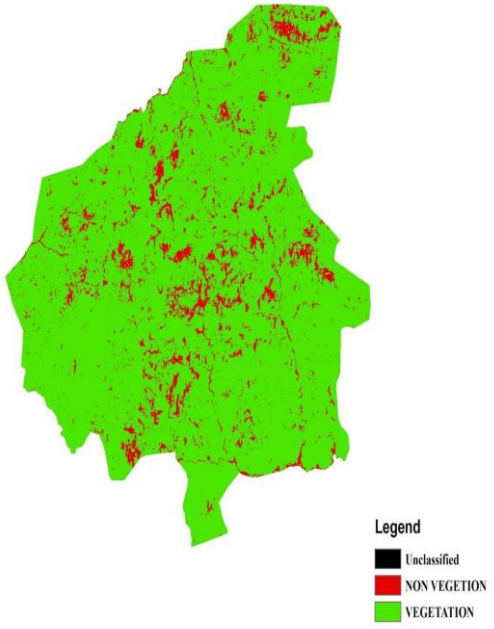
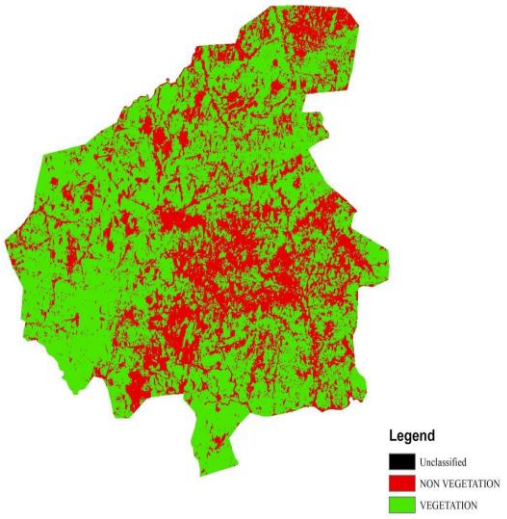


Figure 3: Satellite image showing Tsanyawa LGA as at 2024, having non-vegetation cover of 168.2km^2 (34.2%), vegetation cover of 323.8km^2 (65.8%)



3.1 Discussion of NDVI Analysis (2004–2024)

The Normalized Difference Vegetation Index (NDVI) classification applied to satellite imagery for the Tsanyawa Local Government Area (LGA) between 2004 and 2024 revealed significant changes in land cover, particularly vegetation. NDVI is a widely used remote sensing technique that quantifies vegetation by comparing the difference between near-infrared (which vegetation strongly reflects) and red light (which vegetation absorbs). This analysis classified land cover into **two categories**: **vegetation**, characterised by NDVI values greater than 0.2 (Al Adoski et al., 2013), and **non-vegetation**, which includes bare land, built-up areas, and degraded land.

In 2004, the analysis showed that vegetation covered **449 km²**, accounting for **91.3%** of the total Area, while non-vegetation occupied only **43 km²** (**8.7%**). However, by 2024, vegetation had reduced significantly to **323.8 km²** (**65.8%**), and non-vegetation expanded to **168.2 km²** (**34.2%**). This shift indicates a net loss of **125.2 km²** in vegetated land over the two decades, highlighting a concerning trend of environmental degradation.

The substantial decline in vegetation cover is mainly attributable to increased human activities such as deforestation for agricultural expansion, fuelwood harvesting, infrastructural development, and overgrazing. These factors have intensified over the years, leading to a marked landscape transformation. Field observations and community responses confirm that local farming practices and logging activities are major in the ongoing vegetation depletion.

This trend aligns with global and national reports on land cover changes. Geist and Lambin (2002) emphasized agriculture as a major proximate cause of deforestation worldwide, while the FAO (2020) reported that Nigeria continues to lose forest cover at an alarming rate, particularly in the northern part of the country.

The consequences of vegetation loss in Tsanyawa LGA are multifaceted. Environmentally, it exposes the land to **soil erosion**, **desertification**, and **loss of soil fertility**. It also threatens the ecological balance by reducing biodiversity and altering microclimates. Socio-economically, it stresses rural livelihoods, especially for communities dependent on natural resources for food, fuel, and income.

Although some conservation initiatives, such as tree planting and community awareness campaigns, have been introduced, their impact remains minimal due to poor implementation, inadequate funding, and low public participation. There is a pressing need to strengthen forest governance, promote alternative energy sources to reduce reliance on fuelwood, and engage local stakeholders in reforestation and sustainable land management efforts.

In summary, the NDVI classification results provide clear evidence of vegetation degradation in Tsanyawa over the past two decades. The

region may face severe ecological and socio-economic consequences if current trends persist. Therefore, urgent and coordinated action is needed to restore and sustainably manage the remaining vegetative cover.

3.2

The results from Table 1 show that the demographic profile of the respondents reveals that most respondents are between 31 and 50 years old, with 43.3% aged 31–40 and 35.6% aged 41–50. It suggests that middle-aged individuals are the most engaged or affected by deforestation-related activities. Men dominate the respondent group (72.1%), potentially reflecting greater involvement in land-use practices. Education levels are relatively low, with 76.9% having no more than secondary education, which may influence awareness of sustainable practices. A significant portion (61.5%) are farmers, indicating a close connection between agriculture and deforestation. Additionally, 85.6% live in households of four or more, highlighting the demand for resources like land and fuelwood.

Table 1: Demographic Characteristics of Respondents

Factor	Frequency	Percentage (%)
Age		
< 20	1	1.0
21–30	13	12.5
31–40	45	43.3
41–50	37	35.6
> 50	8	7.7
Gender		
Total	**104**	**100.1**
Male	75	72.1
Female	29	27.9
Educational Level		
Total	**104**	**100.0**
No formal education	36	34.6
Primary school	9	8.7
Secondary school	44	42.3
Tertiary education	15	14.4
Occupation		
Total	**104**	**100.0**
Farmer	64	61.5
Trader	18	17.3
Civil servant	14	13.5
Others	8	7.7
Household Size		
Total	**104**	**100.0**
1–3	6	5.8
4–6	44	42.3
7–10	45	43.3
> 10	9	8.7
Total	**104**	**100.1**

Source: Field Survey,2025

The results from Table 2 show awareness of deforestation is high among the respondents, with 74% acknowledging its presence in their Area. The leading causes cited are agricultural expansion (38.5%), overgrazing (17.3%), and fuelwood collection (16.3%), all of which are tied to livelihoods. Most (90.4%) report that these activities happen frequently or very frequently, suggesting an ongoing and visible threat to the forest. Loggers (30.8%) and farmers (27.9%) are identified as the main contributors, pointing to unsustainable land and forest usage practices within the community.

Table 2: Awareness and Causes of Deforestation

Factor	Frequency	Percentage (%)
Awareness of Deforestation		
Yes	77	74.0
No	26	25.0
Major Causes of Deforestation		
Total	**103**	**99.0**
Agricultural Expansion	40	38.5
Fuelwood Collection	17	16.3
Overgrazing	18	17.3
Logging	16	15.4
Urbanization	13	12.5
Frequency of Contribution		
Total	**104**	**100.0**
Very Frequently	32	30.8
Frequently	62	59.6
Occasionally	7	6.7
Rarely	3	2.9
Group Contributing Most		
Total	**104**	**100.0**
Farmers	29	27.9
Loggers	32	30.8
Herdsmen	18	17.3
Urban Developers	25	24.0
Total	104	100.0

The results from Table 3 show that Deforestation has widespread environmental, social, and economic effects. Environmentally, the most reported consequences are soil erosion (38.5%) and reduced agricultural productivity (36.5%). Socially, nearly half of the respondents (49%) recognize a loss of cultural heritage, while 44.2% note increased land conflicts, revealing tensions

over diminishing natural resources. Economically, reduced crop yields are the most prominent impact, affecting 73.1% of respondents, further underlining the strong link between deforestation and food insecurity.

Table 3: Effects of Deforestation

Factor	Frequency	Percentage (%)
Environmental Effects		
Soil Erosion	40	38.5
Loss of Biodiversity	14	13.5
Reduced Agricultural Productivity	38	36.5
Water Scarcity	7	6.7
Climate Variability	5	4.8
Social Impacts		
Total	**104**	**100.0**
Migration	5	4.8
Increased Conflict over Land	46	44.2
Loss of Cultural Heritage	51	49.0
Economic Impacts		
Total	**102**	**98.0**
Decline in Income	13	12.5
Increased Cost of Wood	12	11.5
Reduced Agricultural Yields	76	73.1
Total	**101**	**97.1**

The results from Table 4 show that 78.8% of respondents have experienced a negative impact on their livelihood due to deforestation. In comparison, 63.5% are aware of existing initiatives to control deforestation, and only 45.2% believe these efforts are practical. The primary obstacles to success include poor community participation (40.4%) and insufficient funding (21.2%). These figures suggest that although efforts are underway, they are not achieving their full potential due to limited resources and engagement from the local population.

Table 4: Control Strategies and Community Involvement

Factor	Frequency	Percentage (%)
Livelihood Impact		
Negatively	82	78.8
No Effect	18	17.3
Positively	2	1.9

Awareness of Initiatives		
Total	**102**	**98.0**
Yes	66	63.5
No	37	35.6
Known Initiatives		
Total	**103**	**99.1**
Community Reforestation	38	36.5
Government Policies	25	24.0
Awareness Campaigns	8	7.7
Effectiveness Belief		
Total	**71**	**68.2**
Yes	47	45.2
No	26	25.0
Challenges		
Total	73	70.2
Lack of Funding	22	21.2
Poor Community Participation	42	40.4
Policy Enforcement Issues	8	7.7
Total	72	69.3

Source: Field Survey,2025

The results from Table 5 show strong community support for solutions to combating deforestation in the study area. Most respondents (64.4%) recommend afforestation, while others support tree planting and related efforts. Solar energy (45.2%) and gas (42.3%) are preferred alternatives to fuelwood, showing an openness to sustainable energy if access is improved. Importantly, 47.1% are willing to join tree planting programs, and 44.2% are ready to reduce firewood usage. A promising 68.3% express willingness to participate in community-based forest management, indicating high potential for grassroots involvement in environmental conservation.

Table 5: Suggestions and Solutions

Factor	Frequency	Percentage (%)
Suggested Measures		
Afforestation	67	64.4
Tree Planting	7	6.8
Others	3	2.9
Alternative Energy Sources		

Total	**77**	**74.1**
Solar Energy	47	45.2
Gas	44	42.3
Others	13	12.5
Community Contributions		
Total	**104**	**100.0**
Tree Planting Participation	49	47.1
Reduce Firewood Usage	46	44.2
Reporting Illegal Logging	9	8.7
Willingness to Join Program		
Total	**104**	**100.0**
Yes	71	68.3
No	33	31.7
Total	**104**	**100.0**

Source: Field Survey,2025

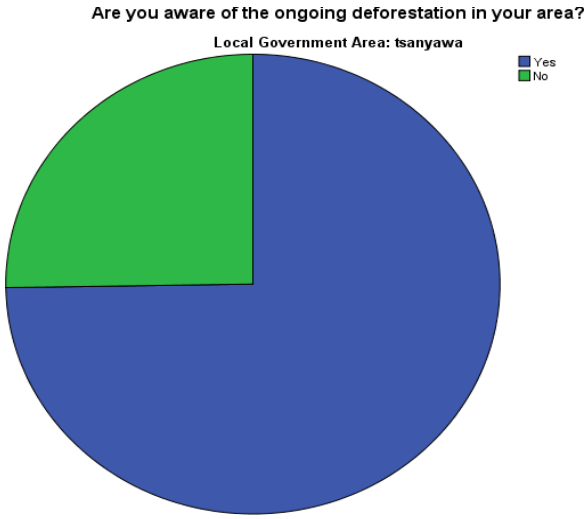
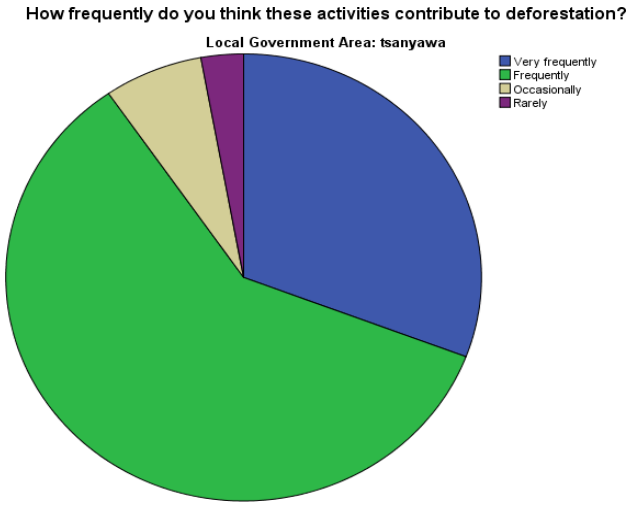


Figure 4



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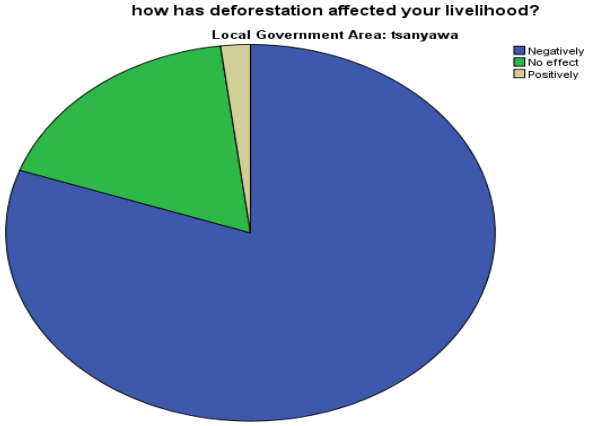


Figure 6

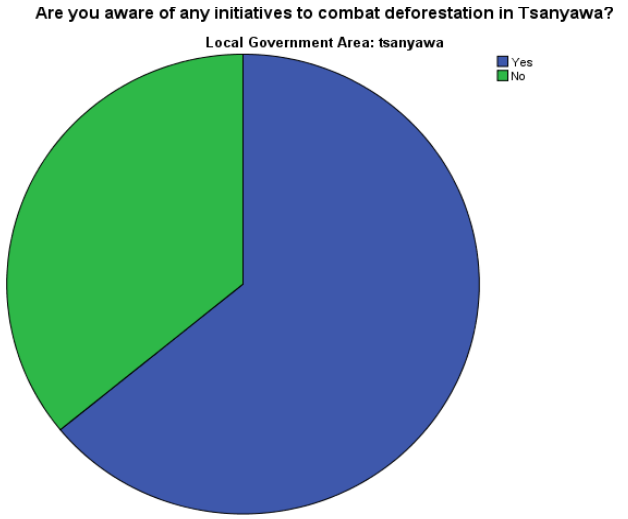
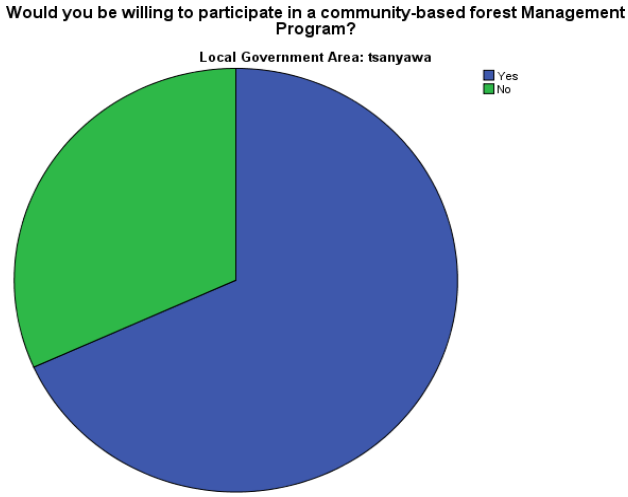


Figure 7



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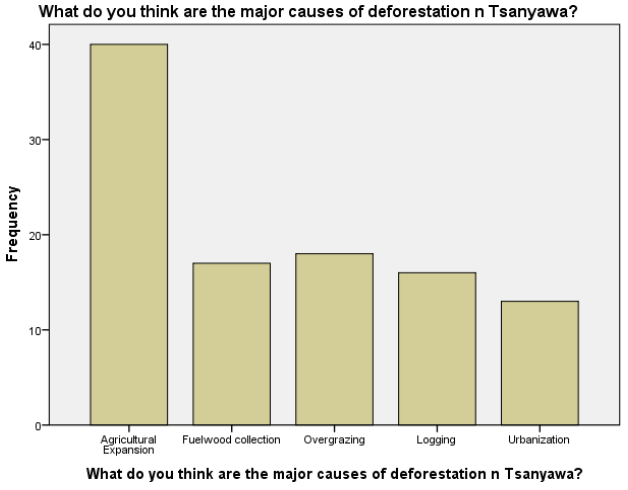


Figure 9

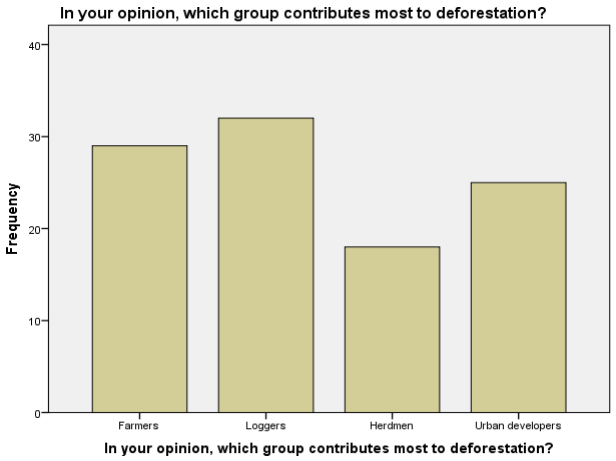
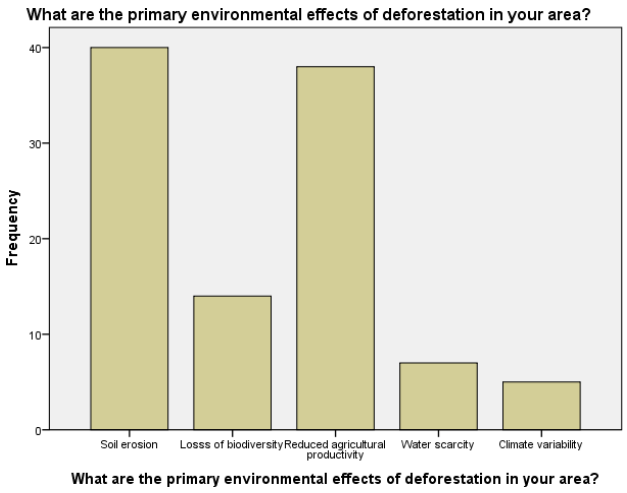


Figure 10



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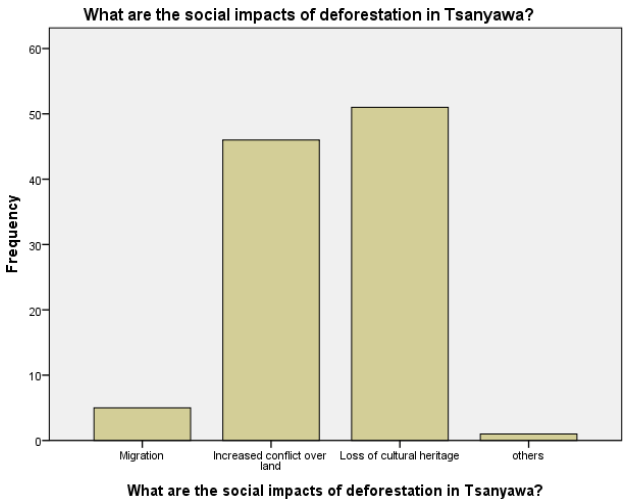

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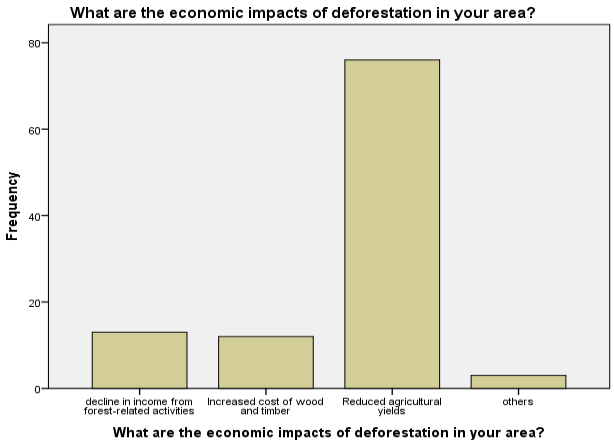


Figure 13

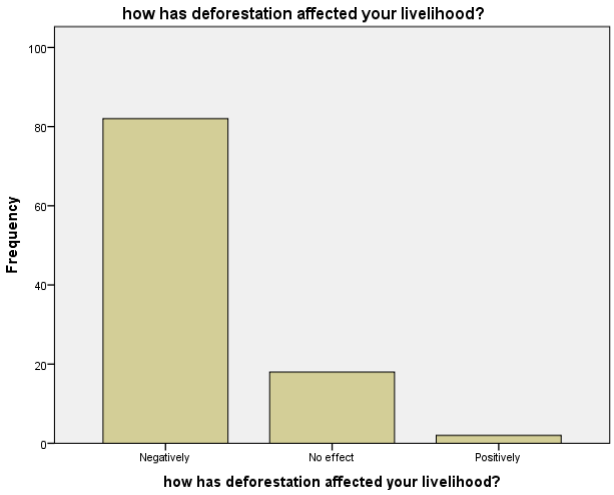
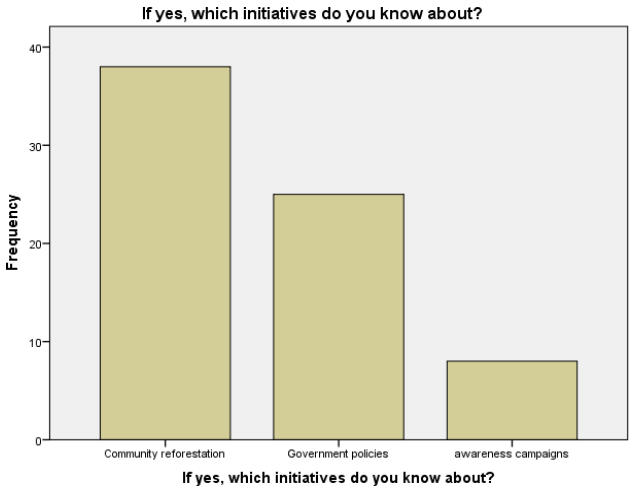


Figure 14



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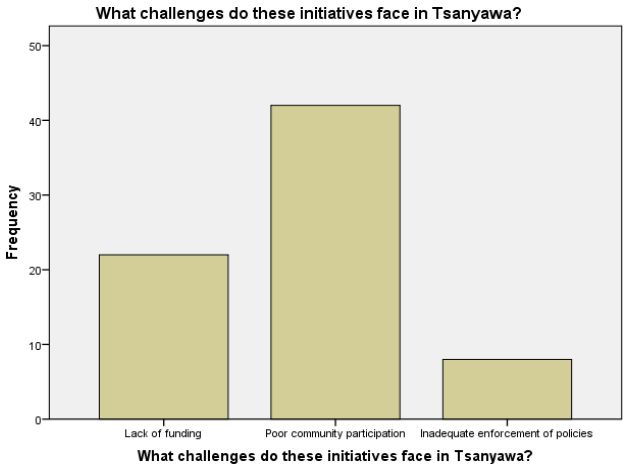

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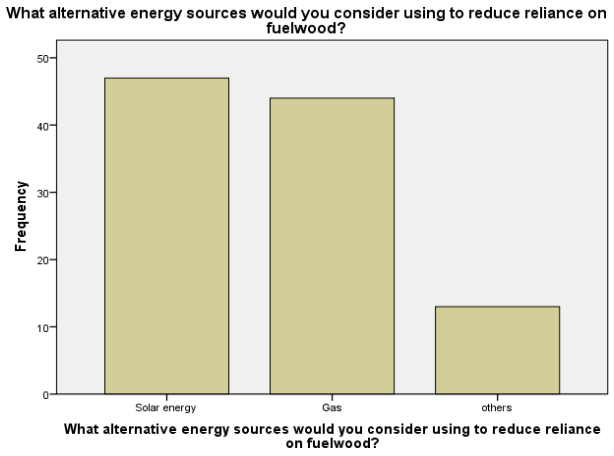

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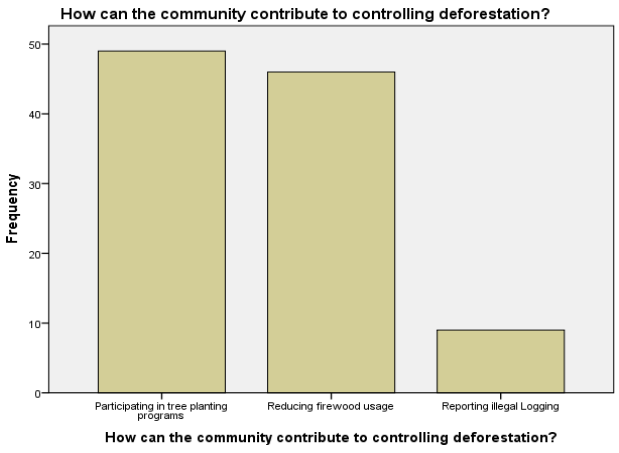

Figure 18

3.3 DISCUSSIONS

The majority of respondents were between 31–40 years (43.3%) and 41–50 years (35.6%), indicating that middle-aged individuals—likely to have lived long enough to notice changes in forest cover—dominate the population. This finding is consistent with the study by Adewuyi and Badmus (2020), who found that middle-aged adults were the most responsive demographic in studies on environmental degradation due to their direct involvement in agricultural practices and natural resource use.Regarding gender distribution, 72.1% were male while 27.9% were female. It suggests that men may be more engaged in land-use activities such as farming, logging, and grazing, an observation that aligns with Ekanade (2015), who noted that in rural Nigerian communities, men often dominate physically demanding land-use practices. In contrast, Okoli et al. (2018) observed a more balanced gender involvement in some southern Nigerian regions where women participate equally in farming and firewood gathering, indicating regional variation in gender roles. 34.6% had no formal education, and 42.3% only completed secondary education. It aligns with Irohibe and Agwu (2014), who reported that low educational attainment is prevalent in rural communities and is often associated with poor environmental awareness. The findings suggest improved educational outreach to promote sustainable land-use practices.Farming was the dominant occupation among respondents (61.5%), followed by trading (17.3%) and civil service (13.5%). It supports Ogunleye et al. (2010), who concluded that rural deforestation in Nigeria is strongly linked to subsistence farming. Large household sizes were also common, with 43.3% having 7–10 members and 42.3% having 4–6. It is consistent with the findings of Agwu and Okhimamhe (2009), who argued that larger family sizes contribute to increased forest resource consumption, especially for domestic energy and farming.On deforestation awareness, 74% of respondents acknowledged ongoing deforestation in their Area. It aligns with Nwoboshi (2000), who found high levels of

awareness in deforestation-prone communities due to visible environmental degradation such as loss of vegetation and soil fertility.Agricultural expansion (38.5%) was cited as the leading cause of deforestation. It supports Geist and Lambin (2002), who identified agricultural land expansion as the foremost global driver of deforestation. Similarly, fuelwood collection (16.3%) and overgrazing (17.3%) were major contributing factors. These findings are consistent with Olagunju (2015), who emphasized the role of energy poverty and livestock pressure in degrading Nigeria's forest reserves. Logging (15.4%) and urbanization (12.5%) were also identified, in line with Chinweze and Abiola-Oloke (2009), who linked population growth and infrastructural development to forest loss.The frequency of deforestation was perceived to be high, with 59.6% indicating it occurs frequently and 30.8% saying it occurs very frequently. It reflects the findings of FAO (2020), which noted accelerated deforestation rates in northern Nigeria due to unsustainable resource extraction. Respondents identified loggers (30.8%), farmers (27.9%), urban developers (24%), and herders (17.3%) as key drivers of deforestation. This distribution closely mirrors Adesina et al. (2018), who noted similar actors in Nigeria's forest decline, especially the role of informal loggers and nomadic herders. In terms of environmental impacts, soil erosion (38.5%) and reduced agricultural productivity (36.5%) were the most prominent, which aligns with Adeyoju (2001), who linked forest loss to topsoil erosion and reduced land fertility. Biodiversity loss (13.5%), water scarcity (6.7%), and climate variability (4.8%) were also mentioned—findings that support the assertions of Ayuba et al. (2007) on how deforestation exacerbates local climate stress.Social impacts such as loss of cultural heritage (49%) and increased conflict over land (44.2%) were significant. These findings agree with Omotayo and Musa (2013), who documented cultural and communal conflicts tied to northern Nigeria's forest access and land competition. While only 4.8% reported migration due to deforestation, it remains a potential long-term consequence, as observed in other studies like Ume (2016).Economically, the most significant impact reported was reduced agricultural yield (73.1%), followed by income decline from forest-based activities (12.5%) and rising timber/firewood costs (11.5%). It aligns with Onyekwelu et al. (2012), who showed how forest depletion impacts both household income and market prices for wood products.On forest conservation, 63.5% of respondents were aware of control initiatives such as community reforestation (36.5%) and government policies (24%). However, only 45.2% considered these effective. This observation agrees with Oladipo et al. (2018), who argued that most forest policies in Nigeria suffer from weak implementation and low community ownership. Poor community participation (40.4%) and lack of funding (21.2%) were the main challenges, issues similarly highlighted in UNEP reports (2019) on forest governance in West Africa.Encouragingly, 68.3% of respondents showed willingness to participate in forest management initiatives, which aligns with Arowolo and Adetula (2013), who noted the positive impact of community-based forest management in areas where local stakeholders are empowered. The preferred alternatives to firewood were solar energy (45.2%) and gas (42.3%), consistent with Ibitoye (2011), who found that access to clean energy reduces deforestation in rural settings.

4. Conclusion

The findings of this study indicate that deforestation in Tsanyawa LGA is driven primarily by **agriculture, fuelwood collection, logging, and urbanisation**, leading to significant **environmental degradation, economic losses, and social conflicts**. Despite awareness of control initiatives, **their effectiveness is limited by funding constraints, low community involvement, and weak enforcement of policies**. The results suggest an urgent need for **sustainable land management practices**, **afforestation programs**, and **stronger policy implementation** to curb deforestation and its negative impacts.

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SUB-THEME 4: ADAPTIVE SILVICULTURAL PRACTICES FOR CLIMATE RESILIENCE AND FOREST SUSTAINABILITY

ASSESSMENT OF NUTRIENT ELEMENT SYNERGY IN THE EARLY GROWTH PERFORMANCE OF *Parkia biglobosa* (Jacq) IN AN ALFISOL AT FORESTRY RESEARCH INSTITUTE OF NIGERIA

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ABSTRACT

The study was conducted in a screen house at the Soils and Tree Nutrition Section of the Forestry Research Institute of Nigeria to determine the nutrient requirements and the effect of mineral deficiencies on *Parkia biglobosa* in degraded soil under nursery conditions. Soil samples were collected from the arboretum of the Institute, which had been degraded. The soil was air-dried and passed through a 2 mm diameter sieve before being filled into poly-pots with a 2 kg soil capacity. The nutrient solutions were formulated using the Minus-one technique (MOET). The experiment was laid out in a completely randomized design with sixteen (16) treatments replicated three (3) times. Plant height, stem diameter, number of leaves, and dry matter yield were assessed at two-week intervals starting from two weeks after transplanting. The data collected were subjected to Analysis of Variance, and Means were separated using the DMRT at a 5% level of probability. The results showed that the phosphorus in the initial soil was sufficient to support plant growth without the need for external supplementation. Nitrogen deficiency in the – N nutrient solution also significantly reduced the plant stem diameter (0.76 – 1.09 mm) from 6 – 16 WAT compared to the results obtained from plants of every other nutrient element combination during the same period. Meanwhile, from 10-16 WAT, the plant supplied with a +K nutrient element combination recorded the highest values for stem diameter (3.07–4.49 mm) compared to all other nutrient element combinations. It is therefore recommended that nitrogen and potassium fertilizers be applied to enhance the early growth of *Parkia biglobosa* in degraded soils.

Keywords: Degraded soil, nutrient, dry matter yield, plant height, *Parkia biglobosa*

INTRODUCTION

One of the most critical aspects of soil use and management is maintaining soil productivity, which is influenced by the soil's nutrient status or fertility (Kyuma, 1996). Plants require 16 essential elements. Carbon, hydrogen, and oxygen are derived from the atmosphere and soil water. The remaining 13 essential elements (nitrogen, phosphorus, potassium, calcium, magnesium, sulfur, iron, zinc, manganese, copper, boron, molybdenum, and chlorine) are supplied either from soil minerals and soil organic matter or by organic or inorganic fertilizers.

(Silva and Uchida, 2000). In plant nutrition, there is a principle known as Liebig's Law of the Minimum. It is named after its author, Justus von Liebig, who said that the growth of a plant is limited by the nutrient that is in the shortest supply. Once its supply is improved, the subsequent limiting nutrient controls plant growth. A plant can also produce to its full potential when all nutrients are at an optimal level, i.e., without any deficiencies or excesses. To produce high yields, plant

nutrition requires a continuous effort to eliminate limiting factors and provide balanced nutrition in the optimal range. Recently, a biological method known as the minus-one element technique (MOET) was developed by PhilRice (Descalsota *et al,* 1999, 2001, 2003). MOET is based on the principle that plant growth responds to the most limiting nutrients. Results of past studies (Descalsota *et al., 1999) showed that MOET was able to identify deficiencies that could* not be checked by soil analysis. *Parkia biglobosa* is a dicotyledonous angiosperm that belongs to the family Fabaceae. It is categorised under spermatophytes and vascular plants. (Thiombiano *et al.,* 2012). It is a deciduous perennial that grows up to seven to twenty meters high. The tree of *Parkia biglobosa* is a fire-resistant heliophyte characterised by its thick, dark grey–brown bark. The pods are commonly referred to as locust beans, measuring approximately 30-40 centimetres in length on average, with some specimens reaching a length of around 45 centimetres. (Teklehaimanot, 2004). The seed of this tree is very rich in nutrients like protein (35%), lipid (29%), and carbohydrate (16%). It also serves as a good source of fat and calcium for rural dwellers. (Ntui *et al.,* 2012). The fruit pulp, leaves, and seeds are used to feed livestock and poultry. The flowers are attractive to bees, which serve as a good source of nectar. (Heuze *et al,* 2018). The seed also serves as a source of income for many women when it is sold after processing for use as a food ingredient (Teklehaimanot, 2004). It is used for treating hypertension, as an anti-malarial plant, and also for wound healing. (Karou, *et al*., 2011). The application of knowledge on the optimum nutrient requirements of tree species is expected to improve economic productivity (Troch and Thompson, 1993). Hitherto, there is a paucity of information on the soil nutrient requirement of these species compared to those of crops. In this context, the study was conducted to determine nutrient requirements and record the effect of mineral deficiencies and the effect of a superabundance of a particular nutrient under nursery conditions.

METHODOLOGY

The study was carried out in a screen house at the Soils and Tree Nutrition department of the Forestry Research Institute of Nigeria (FRIN), located on the longitude 07 º 23’18” N to 07 º 23’43” N and latitude 03 º 51’20” E to 03 º 23’43”43E. Soil samples were collected from the degraded arboretum of the Institute. The soil was air-dried and passed through a 2 mm diameter sieve before being filled into poly-pots with a 13 cm x 23 cm dimension and a 2 kg soil capacity. Pre-germinated seedlings in topsoil were then transplanted at the 4-leaf stage into pre-filled poly pots and watered with a nutrient solution. The nutrient solutions were formulated using the Minus-one technique (MOET) (Descalsota *et al.,* 2001). These nutrients used were Nitrogen, Phosphorus, Potassium, Calcium, Magnesium, Zinc, and Boron. Stock solutions of each nutrient were prepared, and the nutrient solution used was then prepared by diluting 1 mL of stock with 1 L of distilled water. The experiment was laid out in a completely randomized design with sixteen (16) treatments replicated three (3) times. The treatment definition and summary of nutrient solution composition are presented in Table 1.

Table 1: The treatment definition/ summary of nutrient solution composition

S/NO	Treatment	KNO_3	$Ca(NO_3)_2$	$Cacl_2$	K_2SO_4	$MgSO_4$	$Mg(NO_3)_2$	NaH_2PO_4	ZnO	BO_4^-
1	Complete	✓	✓	-	-	✓	-	✓	✓	✓
2	-N	-	-	✓	✓	✓	-	✓	✓	✓
3	-P	✓	✓	-	-	✓	-	-	✓	✓
4	-K	-	✓	-	-	-	✓	✓	✓	✓
5	-Ca	✓	-	-	-	-	✓	✓	✓	✓
6	-Mg	✓	✓	-	-	-	-	✓	✓	✓
7	-Zn	✓	✓	-	-	✓	-	✓	-	✓
8	-B	✓	✓	-	-	✓	-	✓	✓	-
9	+N	✓	✓	-	-	-	✓	✓	✓	✓
10	+P	✓	✓	-	-	✓	-	✓✓	✓	✓
11	+K	✓	✓	-	✓	✓	-	✓	✓	✓
12	+Ca	✓	✓	✓	-	✓	-	✓	✓	✓
13	+Mg	✓	-	✓	-	✓	✓	✓	✓	✓
14	+Zn	✓	✓	-	-	✓	-	✓	✓✓	✓
15	+B	✓	✓	-	-	✓	-	✓	✓	✓✓
16	Control	-	-	-	-	-	-	-	-	-

The growth variables: plant height, stem diameter, number of leaves, and dry matter yield were assessed at two-week intervals starting from two weeks after transplanting. The data collected were subjected to Analysis of Variance, and Means were separated using the DMRT at a 5% level of probability.

RESULTS AND DISCUSSION

The soil used for the research was loamy sand (USDA, 2010). However, the soil was deficient in total nitrogen and had low available P content (ENDMEMO, 2015), (Bloom, 2015) which could retard crop development (Table 2).

Table 2: Initial soil analysis

PARAMETERS	VALUES
Na (Cmol/kg)	1.35
K (Cmol/kg)	0.0010
Ca (Cmol/kg)	0.75
Cu (mg/kg)	8.63
Zn (mg/kg)	14.12
Mn (mg/kg)	67.37
Fe (mg/kg)	27.5
Avail. P (mg/kg)	4.1

O.C (%)	2.07
T.N (%)	0.18
pH (1:2)	6.23
% Sand	80.50
% Silt	8.8
% Clay	10.7

The results on the effect of plant nutrient element combinations on the early growth response of Parkia biglobosa showed that different combinations of nutrients significantly affected the plant growth response at successive growth stages. At 2 - 10 weeks after transplanting (WAT), the plant height obtained from the plant in the control soil (without nutrient application) recorded the highest plant height (19.07 – 24.02 cm) compared with others while the least height (6.67 – 7.07 cm) during the same period was observed from -N nutrient solution (Table 3). It showed that at such an early stage, the concentration of each nutrient in the plant system was adequate except for nitrogen, which is required in large quantities for rapid vegetative growth (Bloom, 2015).

The inhibited growth observed with the –N nutrient solution could also be attributed to a negative interaction of nutrient elements in the absence of nitrogen, which had also reduced the demand for other nutrient elements by the plant (Wilkinson *et al.,* 1999). From 12 – 16 WAT, plant height obtained from the plant supplied with –P recorded the highest plant height (25.00 – 26.50 cm) which is significantly higher than those supplied with –N and +Zn nutrient solutions (7.57, 8.47 and 14.67 cm) at 12 – 16 WAT respectively (Table 3). It suggests that the phosphorus concentration in the initial soil is sufficient for the growth of *Parkia biglobosa,* while further increases (luxury) did not translate to higher plant height.

Table 3: Effect of nutrient combinations on *Parkia biglobosa* plant height (cm)

Treatment	2WAT	4WAT	6WAT	8WAT	10WAT	12WAT	14WAT	16WAT
B-	16.67^{ab}	19.50^{ab}	20.37^{a}	23.00^{a}	23.67^{ab}	25.23^{a}	25.67^{a}	25.33^{ab}
B+	17.00^{ab}	18.17^{ab}	18.67^{ab}	19.63^{ab}	20.50^{ab}	20.67^{a}	21.73^{a}	21.70^{ab}
Ca-	14.10^{ab}	16.00^{ab}	16.20^{ab}	18.33^{ab}	19.57^{ab}	21.40^{a}	22.93^{a}	23.73^{ab}
Ca+	18.50^{ab}	20.00^{ab}	21.17^{a}	23.00^{a}	24.30^{a}	24.70^{a}	24.50^{a}	24.10^{ab}
CP	15.33^{ab}	18.63^{ab}	19.77^{a}	20.83^{ab}	21.23^{ab}	22.27^{a}	23.73^{a}	24.00^{ab}
CT	19.07^{a}	21.00^{a}	22.30^{a}	23.50^{a}	24.20^{a}	24.27^{a}	24.83^{a}	25.17^{ab}
K-	13.27^{bc}	14.43^{b}	15.17^{ab}	16.50^{ab}	17.90^{ab}	18.00^{a}	18.13^{ab}	19.60^{ab}
K+	16.83^{ab}	18.33^{ab}	20.03^{a}	21.67^{ab}	22.03^{ab}	22.87^{a}	23.30^{a}	23.50^{ab}
Mg-	15.17^{ab}	17.40^{ab}	18.47^{ab}	19.53^{ab}	20.93^{ab}	21.50^{a}	22.07^{a}	22.33^{ab}
Mg+	15.50^{ab}	17.93^{ab}	18.67^{ab}	18.77^{ab}	20.57^{ab}	22.13^{a}	23.77^{a}	25.30^{ab}
N-	06.67^{c}	6.77^{c}	6.83^{c}	6.93^{c}	7.07^{b}	7.57^{b}	8.47^{b}	8.67^{bc}
N+	16.30^{ab}	19.83^{ab}	20.43^{a}	21.87^{ab}	23.07^{ab}	23.33^{a}	24.30^{a}	24.60^{ab}
p-	17.40^{ab}	19.23^{ab}	19.90^{a}	22.07^{ab}	22.90^{ab}	25.00^{a}	26.50^{a}	26.50a
P+	15.00^{ab}	16.60^{ab}	17.17^{ab}	19.00^{ab}	20.73^{ab}	22.17^{a}	22.40^{a}	23.00^{ab}
Zn-	13.33^{abc}	15.40^{ab}	16.17^{ab}	18.83^{ab}	20.60^{ab}	20.90^{a}	20.83^{a}	21.47^{ab}
Zn+	11.00^{c}	14.27^{b}	10.57^{bc}	12.83^{bc}	13.50^{bc}	14.77^{ab}	14.77^{ab}	14.67^{bc}

Means followed by the same letter in each column are not significantly different from each other (P>0.05)

Furthermore, Nitrogen deficiency in the –N nutrient solution also significantly reduced the plant stem diameter (0.76 – 1.09 mm) from 6 – 16 WAT compared to the results obtained from plants of every other nutrient element combination during the same period (Table 4). Meanwhile, from 10 to 16 WAT, the plant supplied with a +K nutrient element combination recorded the highest values for stem diameter (3.07–4.49 mm) compared to all other nutrient element combinations (Table 4). It is in line with the submission of Ashley and Goodson (1972) that an Adequate K level is essential for the efficient use of N in crop plants, which in turn could be responsible for the increase in plant stem diameter.

Table 4: Effect of nutrient combinations on *Parkia biglobosa* plant Stem diameter (mm)

Treatment	2WAT	4WAT	6WAT	8WAT	10WAT	12WAT	14WAT	16WAT
B-	2.25^{ab}	2.33^{ab}	2.41^{a}	2.44^{a}	2.85^{a}	3.31^{ab}	3.51^{ab}	4.01^{a}
B+	2.12^{ab}	2.19^{ab}	2.34^{a}	2.503^{a}	2.73^{a}	3.07^{ab}	2.94^{ab}	3.62^{a}
Ca-	1.82^{bc}	1.94^{abc}	2.21^{ab}	2.10a-d	2.25^{ab}	2.70^{ab}	2.84^{ab}	3.41^{a}
Ca+	2.167^{ab}	2.23^{ab}	2.36^{a}	2.46^{a}	2.83^{a}	3.3^{ab}	3.65^{a}	4.03^{a}
CP	2.1^{ab}	2.23^{ab}	2.31^{a}	2.34^{a}	2.70^{ab}	3.10^{ab}	3.12^{ab}	3.76^{a}
CT	1.95^{abc}	2.07^{abc}	2.18^{ab}	2.24a-d	2.66^{ab}	2.92^{ab}	3.13^{ab}	3.71^{a}
K-	1.91^{abc}	2.03^{abc}	2.17^{ab}	2.06a-d	2.19^{ab}	2.65^{ab}	2.85^{ab}	3.27^{a}
K+	2.12^{ab}	2.36^{a}	2.41^{a}	2.51^{a}	3.07a	3.53^{a}	3.61^{ab}	4.49^{a}
Mg-	2.09^{ab}	2.34^{ab}	2.62^{a}	2.28^{ab}	2.41^{ab}	2.78^{ab}	3.21^{ab}	3.68^{a}
Mg+	2.07^{abc}	2.31^{ab}	2.48^{a}	2.52^{a}	2.90^{a}	2.83^{ab}	3.10^{ab}	3.64^{a}
N-	1.73^{bc}	1.28^{c}	0.76^{c}	0.79^{d}	0.94^{c}	0.98^{c}	0.93^{c}	1.09^{b}
N+	1.91^{abc}	2.12^{ab}	2.26^{a}	2.15a-d	2.46^{ab}	2.97^{ab}	3.03^{ab}	3.68^{a}
p-	2.02^{abc}	2.11^{ab}	2.34^{a}	2.283^{abc}	2.46^{ab}	2.77^{ab}	3.22^{ab}	3.47^{a}
P+	1.95^{abc}	2.23^{ab}	2.29^{a}	2.24a-d	2.51^{ab}	2.80^{ab}	3.19^{ab}	3.53^{a}
Zn-	2.55^{a}	2.61^{a}	2.69^{a}	2.42^{a}	2.6^{ab}	3.11^{ab}	3.38^{ab}	4.39^{a}
Zn+	1.42^{c}	1.50^{bc}	1.29^{ab}	1.287^{bcd}	1.36^{bc}	1.87^{bc}	2.11^{bc}	2.77^{a}

Means followed by the same letter in each column are not significantly different from each other (P>0.05)

Similarly, an adequate level of N and P was shown to increase the plant's number of leaves (29), but the plant with a –B nutrient combination had an average of 33 leaves at the end of the study (Table 5). It suggests that boron is most likely to have an antagonistic effect on the leaf production of *Parkia biglobosa.* The plant supplied with the N nutrient solution also recorded the least number of leaves throughout the study (Table 5). It further confirms the essentiality of nitrogen in plant production.

Table 5: Effect of nutrient combinations on the number of leaves of the *Parkia biglobosa* plant

Treatment	2WAT	4WAT	6WAT	8WAT	10WAT	12WAT	14WAT	16WAT
B-	12[a]	17[a]	19[ab]	24[a]	29[a]	31[a]	32[a]	33[a]
B+	12a	16[ab]	17[ab]	20[a]	22[a]	26[ab]	29[a]	23[ab]
Ca-	11[a]	14[ab]	16[ab]	23[a]	27[a]	28[ab]	31[a]	27[a]
Ca+	13[a]	15a-d	18[ab]	22[a]	25[a]	28[ab]	24[a]	25[ab]
CP	13[a]	18[a]	18[ab]	22[a]	25[a]	25[ab]	25[a]	27[a]
CT	11[a]	14a-d	16[ab]	19[a]	23[a]	25[ab]	24[a]	26[ab]
K-	12[a]	13a-d	15[ab]	21[a]	25[a]	28[ab]	28[a]	23[ab]
K+	11[a]	15a-d	21[a]	25[a]	27[a]	29[ab]	28[a]	25[ab]
Mg-	13[a]	13a-d	16[ab]	20[a]	26[a]	26[ab]	24[a]	20[ab]
Mg+	10[a]	13a-d	15[ab]	21[a]	24[a]	30[ab]	27[a]	26[ab]
N-	9[a]	4[d]	6[c]	6[b]	6[b]	7ab	9[b]	11[b]
N+	10[a]	12a-d	15[ab]	20[a]	21[a]	28[ab]	28[a]	29[a]
P-	11[a]	14a-d	15[ab]	16[ab]	21[a]	24[ab]	24[a]	25[ab]
P+	14[a]	16a-c	18[ab]	22[a]	24[a]	29[ab]	29[a]	29[a]
Zn-	11[a]	15a-d	18[ab]	23[a]	26[a]	29[ab]	27[a]	27[a]
Zn+	9[a]	8b-d	10[bc]	15[ab]	17[ab]	18[b]	20[bc]	18[ab]

Means followed by the same letter in each column are not significantly different from each other (P>0.05)

Table 6 shows the effect of nutrient elements combination on the shoot and root dry matter yield (DMY) of *Parkia biglobosa.* There was no significant difference in the shoot DMY data obtained. Still, the plants supplied with +K and +N recorded the highest DMY (2.05 and 2.15 g), compared to those of –N and +Zn (0.77 and 0.92 g), which had the lowest values. In comparison, a similar trend was also observed in the plant root DMY, where plants supplied with +K recorded a significantly higher root DMY (1.90 g) compared to those supplied with +Zn (0.74 g) (Table 6).

Table 6: Effect of nutrient combinations on *Parkia biglobosa* plant dry matter yield (g)

Trt	SHOOT	ROOT
B-	1.59	1.59^{ab}
B+	1.71	1.48^{ab}
Ca-	1.19	1.75^{ab}
Ca+	1.66	1.56^{ab}
Cp	1.32	1.14^{abc}
CT	1.59	1.64^{ab}
k-	1.67	1.15^{abc}
k+	2.05	1.90^{a}
Mg-	1.37	1.63^{ab}
Mg+	1.59	1.73^{ab}
N-	0.77	0.39^{c}
N+	2.15	1.73^{ab}
p-	1.69	1.79^{ab}
P+	1.46	1.23^{abc}
Zn-	1.30	1.27^{abc}
Zn+	0.92	0.74^{bc}

Means followed by the same letter in each column are not significantly different from each other (P>0.05)

CONCLUSION AND RECOMMENDATIONS

The early growth response of Parkia biglobosa was inhibited by the absence of nitrogen in the nutrient solution, whereas the absence of phosphorus in the applied solution was not a limiting factor affecting the plant's early growth, resulting in a higher plant height. An increase in Nitrogen and Potassium concentrations in the applied nutrient solutions improved the plant shoot dry matter yield. In contrast, the plant root dry matter yield was significantly improved with the application of excess potassium. It is therefore recommended that nitrogen and potassium are essential for the early growth and production of *Parkia biglobosa* in the study.

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COMPARATIVE STUDIES ON DORMANCY BREAKING METHODS ON GERMINATION OF TWO SAVANNAH TREE SPECIES.

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Abstract

The research was conducted at the nursery site of the Department of Forestry and Environmental Technology, School of Agriculture, Hussaini Adamu Federal Polytechnic, Kazaure, to evaluate the germination studies of some selected multipurpose tree species (Tamarindus indica L. and Parkia biglobosa Benth. Found in the Sudan savannah region of Nigeria. Four treatments were used (Sulphuric acid, boiling water, and Boiled water (24 hr) at different levels and control. The (TR1, TR2 and TR3), Boiling water (TR4, TR5 and TR6), (TR7) at varying duration and (TR8). The result of the study revealed that, sulphuric acid treatment performed very well for breaking seed dormancy of the two tree species in which (TR3) duration emerged in 6 and 7 days after sowing and was later (TR1) and (TR2) duration in 7 and 8 days emerged to T. indica and P. biglobosa seeds. The (TR6) duration emerged in 9 days after sowing for the two study species. The (TR7) germinated in 10 and 11 days after sowing, and the control emerged in 18 and 20 days after sowing of the study species. The germination percentage of seeds treated with (TR1 and TR2) period produced (90.1% and 85.06%) for T. indica, while P. biglobosa percentage noticed in (TR2 and TR1) duration, with 93.07% and 76.32% respectively, and the least value was found in (TR3) duration (75.07% and 70.45%). The boiling water treatment, which has the highest germination percentage for the two species, occurred in the (TR6) duration (95.1% & 90.26%), compared to the (TR5) (82.09% & 89.28%) and (TR4) period (75.08% & 65.26%). The lowest percentage was noticed in the (TR8). It is therefore recommended that the duration of (TR6) and (TR2) be encouraged for farmers and researchers to break seed dormancy when propagating seedlings in the nursery.

Keyword: Treatment, Seeds, Germination, Savannah, and Multipurpose trees.

Introduction

Seed germination is the emergence of the embryo from the seed, and the germination process is triggered by a variety of anabolic and catalytic activities (Tukur & Kan, 2013; Atiku et al., 2021). Seeds are important starting materials for the propagation of many multipurpose tree species (Oyebamiji et al., 2019). Therefore, the use of seeds as propagules has been considered the easiest, cheapest, and most common means for many agroforestry and timber tree species (Adelani et al., 2014). Seed germination is traditionally described as a process comprising three phases, starting with water intake, during which the seed imbibes and reinitiates metabolic processes, as well as the emergence of the radicle through the seed envelope (Hasnat et al., 2017). It has been documented that a high level of seed dormancy is a characteristic feature of savannah trees, which either prevents germination or leads to patchy germination patterns (Bello et al., 2013). According to Olorunmaiye et al. (2011), seed dormancy is an adaptive mechanism that blocks the germination process of savannah tree seeds

under conditions when the chance of seedling survival and growth is very low (Schmidt, 2000; Oluwafemi et al., 2014; Okpanachi et al., 2019). Seeds of many leguminous plants have hard seed coats, which make it difficult for the seeds to imbibe water and prevent gaseous exchange (Cheikhyoussef et al., 2011). Treatment involves softening seed coats to allow seeds to enlarge during the germination process (Adejumo et al., 2013).

The *Tamarindus indica* tree belongs to the family *Fabaceae* and subfamily Caesalpinioideae, commonly known as Tamarind, and is referred to as Tsamiya in Hausa, within the Kingdom Plantae (Amusa, 2011; Saidu et al., 2019). The seeds have a high forage value; it is a tree that provides good firewood and produces excellent charcoal (Tadros et al., 2011). It is a multipurpose tree species, drought-resistant, and has specific uses for medicinal, shelter, food, as well as windbreak purposes (Saidu et al., 2018). The tree is native to tropical Africa, and grows wild throughout Sudan, where it was later introduced to India, where it became naturalised (Bello & Zubairu, 2015). *T. indica* grows well over a wide range of soil and climatic conditions, occurring in low-altitude woodland, savannah, and bush (Orwa et al., 2009). *T. indica* prefers semi-arid areas and wooded grassland and can also be found along streams and riverbanks (Saidu et al., 2023).

Parkia biglobosa is known as African locust bean (common name), Dorowa in Hausa, and is a perennial deciduous tree of the family Fabaceae (Saidu et al., 2023). The tree ranges in height from 7 m to 20 m and bears a large crown with branches that spread widely (Adejumo et al., 2013). *P. biglobosa*, hitherto denoted by different scientific names, including *P. roxburghii, P. javanica,* and *P. timoriana,* is a tree distributed in India's northeastern region, where people of Manipur consume its food products substantially (Saidu et al., 2019). The fermented seeds are used in all parts of Nigeria and indeed the west coast of Africa for seasoning traditional soups (Orwa et al., 2009). The seeds contain a high protein content and are used as a coffee substitute, with 29% crude protein, 60% saccharose, and Vitamin C (Oyebamiji et al., 2018b; Romeira et al., 2018; Oyebamiji et al., 2021). The tree is multipurpose, providing domestic products and earning income for many rural populations (Mukhtar, 2016). The tree can withstand drought conditions due to its deep taproot system and the ability to restrict transpiration, thereby providing environmental protection and enhancing its beauty (Mojeremane et al., 2017). The tree is also known to provide an ingredient used in the treatment of leprosy and hypertension (Oyebamiji et al., 2018a). The trees occur in a wide range of Natural and semi-natural communities (Tukur & Kan, 2013). The trees prefer well-drained, deep, and cultivated soils, as well as stony ridges, or sandstone hills (Mojeremane et al., 2018; National Research Council (NRC), 2008). *P. biglobosa* is an important indigenous, multipurpose tree species that provides food, medicines, and shade while stabilizing a degraded environment and playing an ecological role in nutrient cycling (Oluwafemi et al., 2014; Oyebamiji et al., 2019).

The study trees remain undomesticated due to a lack of tradition to plant indigenous tree species, as they contribute to the local economy (Mukhtar et al., 2021). Several studies have reported pre-sowing treatments that enhance the germination of multipurpose tree species with hard seed coats (Nadjafi et al., 2006; Pipinus et al., 2011). The techniques of breaking seed dormancy to improve germination within a stipulated time are inadequate (Tadros et al., 2011). This study aimed to compare the germination studies of *P. biglobosa* and *T. indica* under nursery conditions. One of the most significant obstacles to the regeneration of multipurpose tree species is the lack of adequate information on the conditions necessary for their germination. The research suggests the need to use an appropriate method of seed treatment to raise seedlings in nursery conditions before transplanting them to the field.

Materials and Methods

Study Location

The experiment was carried out at the central nursery of the Department of Forestry and Environmental Technology, School of Agriculture, Hussaini Adamu Federal Polytechnic, Kazaure, Jigawa State States in the Sudan Savannah region and lies between Latitude 12^0 39’ 10” N - 12^0 65’ 27.8” N and Longitude 8^0 24’57” E - 8^0 41’ 19.4” E (Saidu et al., 2023). The state is located in the northwestern part of Kano State, approximately 65 km away from the Kano metropolitan area (Kankara, 2014). It also borders Katsina, covering an area of approximately 770.063 Km^2 (Mufida and Sani, 2022). The rainfall pattern is divided into two seasons: a rainy season (June–September) and a dry season (October–May) (Lawal

and Salami, 2018). The average annual rainfall ranged between 700 and 750 mm/a (Kankara and Idris, 2020). The minimum temperature ranged from 23^0 °C to 280 °C, while the maximum temperature ranged from 380 °C to 400 °C °C (Makawa and Suleiman, 2022). It has an average elevation of approximately 250-600 m above sea level (Ibrahim, 2003). The vegetation pattern is predominantly characterised by thorny shrubs and grasses that are less than 2 m high (Gupa et al., 2024). The few tall trees are thorn Acacias, Neem, and Baobabs, which are scattered and normally shed their leaves completely during the dry seasons (Idris, 2012; Saidu et al., 2018). The trees have an average height between 10 and 15 m (Salami et al., 2019). It is denser along river courses due to the presence of moisture, which allows the vegetation to flourish (Saidu et al., 2019). The soil types are Inceptisol, Cambisol, and Gleysols, classified as brown or reddish brown (Shamaki et al., 2015).

Seed collection methods

Seeds were collected from the Department of Forestry and Natural Resources in Katsina State in January 2024. Mature and healthy pods were collected by climbing the mother tree's branches with a long, hooked stick to dislodge them. The collected dry pods were placed in bags and transported to the experimental site (Likoswe et al., 2008; Orwa et al., 2009).

Seeds Extraction Method

Seeds were extracted by hand-crushing the pods, followed by winnowing to separate the seeds from the pods, and a powder obtained (NRC, 2018).

Seeds Treatment Methods

Seeds were kept in a well-ventilated shade for a week before the commencement of the experiments, as adopted from Bello & Zubairu (2015) and Oyebamiji et al. (2021).

Seeds Viability Test

Seeds' viability was tested using the floating method, where viable seeds were selected based on the sinker and floater methods (Mandal, 2000; Singh et al., 2011). Only seeds that sank in water were used for the experiment.

Experimental design and treatments

The study consists of four treatments (sulphuric acid, boiling water, hot water for 24 hours, and control), with seven levels of treatment. The experimental design was laid out in a completely randomized design (CRD) replicated three times.

Germination assessment

Soaked in Conc H_2SO_4 98% 5min (TR1)

Soaked in Conc H_2SO_4 98% 7min (TR2)

Soaked in Conc H_2SO_4 98% 9min (TR3)

Soaked in boiling water for 2 min (TR4)

Soaked in boiling water for 4 min (TR5)

Soaked in boiling water 6 min (TR6)

Soaked in boiled water for 24 hr (TR7)

Untreated seed (TR8)

Soaking seeds in Sulphuric acid (H_2S04)

Three periods of soaking seeds (TR1, TR2, and TR3 min) using concentrated sulphuric acid (98%), described by (Agbogidi et al., 2007; Hasnat, 2017). For each period of soaking, 15 seeds were placed into a 100-ml heat-resistant container containing sulfuric acid, ensuring that the acid covered all the seeds. Seeds were hand-stirred thoroughly for a specified time to ensure uniform soaking in the acid. After the specified periods, the seeds were sieved out using an acid-resistant sieve. The tap water was used to wash and rinse the seeds, removing acid from them (Onthatile et al., 2019).

Soaking seeds in boiling water

Three periods of soaking seeds (TR4, TR5, and TR6 minutes) in boiling water, which was on the heat source, were used. For each period of soaking seeds, 15 seeds were poured into containers of boiling water for the specified periods, after which the seeds were removed a few minutes before sowing (Obiazi, 2015).

Soaking seeds in boiled water for twenty-four hours (TR7)

Fifteenth (15) seeds were containerised, and then, poured into the containers containing boiled water at $100^{0\ °C}$, the water was cooled with the seeds for 24 hours before sowing the seeds. The untreated seeds were used as the control for the entire experiment.

Sowing Substrate

The treated seeds were sown in polyethylene bags measuring 15 x 25 cm, filled with a mixture of topsoil, River sand, and cow dung in a 2:1:1 ratio, respectively (Mukhtar et al., 2021). Watering the mixture for a week to maintain the moisture content of the nursery beds arranged in a Completely Randomised Design (CRD) replicated three (3) times. Each treatment combination consisted of 15 seeds, resulting in a total of 360 seeds for the experiment.

Treatments	**Number of treated seeds sown**
Soaked in Conc H_2SO_4 98% 5min	45
Soaked in Conc H_2SO_4 98% 7min	45
Soaked in Conc H_2SO_4 98% 9min	45
Soaked in boiling water for 2 min	45
Soaked in boiling water for 4 min	45
Soaked in boiling water for 6 min	45
Soaked in boiled water for 24 hr	45
Untreated seed	45

Data collection

The germination rate was assessed daily for twenty days. The seed was considered germinated when the two pairs of cotyledon leaves appeared out of the seed coat. Daily recording of seeds that emerged from the sowing date to the first germination to the end of the germination period (4th week after sowing). Eight (8) different germination rates were assessed. Data collected on the germination of seeds were used to calculate the following

1. Latency time (LT)
2. Germination time (GT)
3. final germination rate (TGF)

Data analyses

The data collected were subjected to descriptive statistics (frequency and percentage)

Table 1: Response of Seeds on Latency Time (LT)

Treatments	**Days of Emergence**	
	T. indica	***P. biglobosa***
Soaked in Conc H_2SO_4 98% 5min	00 –07	00 – 09
Soaked in Conc H_2SO_4 98% 7min	00 –08	00 – 08
Soaked in Conc H_2SO_4 98% 9min	00 –06	00 – 07
Soaked in boiling water for 2 min	00 –10	00 – 12
Soaked in boiling water for 4 min	00 - 09	00 – 11
Soaked in boiling water for 6 min	00 –09	00 – 09
Soaked in boiled water for 24 hr	00 –10	00 – 11
Untreated seeds	00 –18	00 – 20

The latency time (TL) refers to the time elapsed from the sowing date to the first day of witnessing germination. The table indicated that *T. indica* seeds soaked in sulphuric acid (H2S04) in (TR3) duration emerged in six (6) days, followed by (TR1 and TR2) duration, which emerged in 7 and 8 days after sowing. The seeds soaked in (TR6 and TR5) duration emerged in nine days, while seeds soaked in (TR7) and seeds soaked in (TR4) germinated on the same day (10), and the control emerged on eighteen days (18). The seeds of *P. biglobosa* soaked in sulphuric acid (H2S04) in the (TR3) period germinate in seven days, (TR2 and TR1) emerged in eight and nine days after sowing. The seeds soaked in (TR6) duration germinate in nine days, and 2 min duration emerged in twelve days. The seeds soaked in (TR7) and (TR5) duration emerged on the same day after sowing, and the control emerged in twenty days.

Table 2, Response of Seed Treatment on Germination Time (GT)

Treatments	Germination time	
	T. indica	***P. biglobosa***
Soaked in Conc H_2SO_4 98% 5min	07 –28	09 – 28
Soaked in Conc H_2SO_4 98% 7min	08 –28	08 – 28
Soaked in Conc H_2SO_4 98% 9min	06 –28	07 – 28
Soaked in boiling water for 2 min	10 –28	12 – 28
Soaked in boiling water for 4 min	09 - 28	11 – 28
Soaked in boiling water for 6 min	09 –28	09 – 28
Soaked in boiled water for 24 hr	10 –28	11 – 28
Untreated seeds	18 –28	20 – 28

The table above reveals that the germination time is measured as the median time, corresponding to 50% of the seed germination. This measure allows for knowing the germination behaviour of all seeds in a treatment (Yao et al., 2021) in the Shea tree.

Table 3, Response of seed treatment on Final Germination Rate (TGF)

Treatments	Germination percentage (%)	
	T. indica	***P. biglobosa***
Soaked in Conc H_2SO_4 98% 5min	90.11	76.32
Soaked in Conc H_2SO_4 98% 7min	85.06	93.07
Soaked in Conc H_2SO_4 98% 9min	75.07	70.45
Soaked in boiling water for 2 min	75.08	65.26
Soaked in boiling water for 4 min	82.09	89.28
Soaked in boiling water for 6 min	95.10	90.26
Soaked in boiled water for 24 hr	87.09	80.09
Untreated seeds	50.00	45.05

Table 2 explains that the Final germination rate (TGF) refers to the percentage of seeds that have germinated during the germination process.

The soaking method with the highest germination percentage is TR6, which produced 95.1% followed by TR1 (90.1%) and TR7 (87.09%), and the control has the lowest percentage of 50% in *T. indica,* while *P. biglobosa,* the highest percentage noticed in (TR2) duration, 93.07% followed by (TR6 and TR5) duration, produced 90.26 and 89.28 % respectively, and control has the least value of 45.05%.

Days of Emergence

The results showed that seeds of P. biglobosa soaked in sulphuric acid for 9 minutes germinated in seven days of sowing, followed by 7 minutes and 5 minutes of duration, respectively. While T. indica seeds soaked in sulphuric acid for 9 minutes exhibited germination in six days, followed by 5 minutes and 7 minutes of duration, respectively. The seeds of *P. biglobosa*t soaked in Boiling water in (6 min) duration germinate in nine days of sowing follows by others treatments 4 min and 2 min period while *T. indica* seeds emerged in 4 and 6 min duration germinate on the same day after sowing follow by 2 min period which germinate exactly in ten days. Days of emergence noticed eleventh (11) days in *P. biglobosa* and ten (10) days for *T. indica* of the seeds soaked in boiled water treatment (24 hr), and control germinated in eighteenth days for *T. indica* seeds and twenty days for *P. biglobosa* seeds.

Germination percentage

The results showed that seeds treated with sulphuric acid, boiling water, and boiled water (24 hours) had significantly higher germination percentages than the control. *P. biglobosa* seeds treated with sulphuric acid at 7 minutes and boiling water at 6 minutes had significantly higher germination percentages than those treated with boiling water and the control, unlike T. indica, which showed faster germination percentages at 5 minutes and 6 minutes with boiling water than with boiling water and the control. The highest germination percentages were observed at 95.1% boiling water and 90.1% sulfuric acid for T. indica, while *P. biglobosa* indicated the germination percentage highlighted at 7 minutes in sulphuric acid (93.07%) and 6 minutes in boiling water (90.26%).

The average germination percentage reaches 83.41% for *T. indica* seeds treated with sulphuric acid and 79.92% for P. biglobosa, while boiling water treatment yields 84.09% for T. indica and 81.6% for *P. biglobosa*. On the other hand, untreated seeds (control) and seeds treated with boiled water (24 hours) exhibit not only the lowest germination percentage but also the slowest percentage germination.

Discussion

Many researchers have highlighted different Silvicultural techniques for breaking seed dormancy to improve germination rates and speed up the germination process. Results of this study indicated that *P. biglobosa* and *T. indica* are characterized by tree species experiencing physical seed dormancy imposed on the seeds by a water-impermeable seed coat (Saidu et al., 2019).

Sulfuric acid is a dangerous and abrasive chemical that requires careful handling, adhering to all safety rules to protect both the public and the environment during its use (Amusa, 2011). Sulphuric acid (TR1 and TR2) improved seed germination compared with the control in the two study tree species. This finding aligns with those of other researchers, who reported prompt and uniform germination in hard seed-coated seeds soaked in sulphuric acid (Olatunji et al., 2013). Seed germination of *T. indica* and *P. biglobosa* in the present study increased with the soaking period for *P. biglobosa* in sulphuric acid. Oyebamiji et al. (2018b) and Mukhtar et al. (2021) recorded the highest germination in *T. indica L*. seeds soaked in sulphuric acid (50%) for 60 minutes. The sulphuric acid cracks the hard seed coat, allowing water to imbibe the seeds for germination, which is more rapid and uniform, thereby triggering seed germination (Atiku et al., 2021).

The results of the study revealed that the treatments (TR4, TR5, and TR6) on the two study species are supported by similar studies conducted on other leguminous species (Oyebamiji et al., 2018a). However, the (TR4, TR5, and TR6) treatments are more effective methods for many tropical leguminous trees. The present study revealed that (TR6) imposes a germination rate of *T. indica* seeds compared with *P. biglobosa* and the control. Seeds soaked in (TR4) differ significantly from other treatments, and the control has the least value. The result agrees with the findings of Chaodumrikul et al. (2016), which reported that a 2-minute treatment resulted in faster germination of *Adonsonia digitata*. The results align with those of Singh et al. (2022), who found that boiling water for 5 minutes enhanced seed germination in tropical tree species. Oyebamiji et al. (2021) also reported that boiling water for 7 minutes improved the germination percentage in *Vachellia karroo* (Hayne) compared with the control. This result is consistent with Falemara et al. (2014), who reported a decrease in per cent germination with increasing exposure time, up to 5 minutes, using boiling water for *Senegalia galpinii* and *Vachellia robusta.* The result aligns with Obiazi (2015), who found that boiling water for 1 minute softens hard seed coats, leaches out chemical inhibitors, and allows imbibition and gaseous exchange during germination. In the case of *E. africanum,* per cent germination was increased by treating seeds in boiling water (1 minute) compared with the control. Results show that the percentage of germination decreased with an increase in exposure time to boiling water. The results were in line with those reported by Atiku et al. (2021), which revealed that a decline in germination percentage with an increase in boiling period was due to the dryness of the seeds, which might have damaged the embryo.

Botsheleng et al. (2014) reported that treating seeds for (TR7) at 100°C enhanced the germination percentage of *Adansonia digitata* L., *Calliandra calothyrsus* Meissner, and *Sesbania sesban* (*L.*) Merr. The performance of the two tree species in the (TR7) was due to the adequate knowledge on the application of the treatment to break dormancy (Agbogidi et al., 2007). (Azad et al., 2011). The result from this

research revealed that (TR7) was effective in days of emergence and increasing germination percentage in *P. biglobosa* compared with (TR1, TR3, TR4) and the controls. At the same time, *T. indica* in (TR7) softened the seed coats and allowed for the imbibition of water for germination (Aref et al., 2011). The results disagreed with the fact that the percent germination in this species decreased with increasing exposure time, suggesting that physical dormancy was imposed, rather than embryonic dormancy.

Conclusion

It is evident from the study that pre-treatments, such as H_2SO_4 and Boiling water, enhance seed germination of P. biglobosa and T. indica in the nursery, with the highest germination percentages of 93.07% (TR2) and 90.26% (TR6) for P. biglobosa. In comparison, T. indica has 95.1% (TR6) and 90.11% (TR1). Based on the findings, pre-sowing treatment of P. biglobosa and T. indica seeds with sulphuric acid (H2SO4) and Boiling water is recommended for breaking the seed coat dormancy very quickly.

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BAMBOO RESOURCE MANAGEMENT: A VERITABLE MEANS FOR CLIMATE CHANGE MITIGATION

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ABSTRACT

The current change in global temperature has been a significant topic of discussion in recent times, due to its anticipated effects on global economic and industrial development patterns. Notably, tropical deforestation is responsible for nearly one-fourth of annual global carbon dioxide emissions. Climate change has emerged as one of the hotly debated issues in current times. Given the increasing effects of climate change on both human and material resources, it is rapidly dictating economic, production, and consumption activities in different countries, including international trade.

This research therefore examines the impact of climate change on sustainable development such as "on the environment, human health, food security, economic activities, natural resources and physical infrastructure" and highlighted climate change mitigation and adaptation options for developing countries such as Nigeria through bamboo resources management and many other ways the forest in general can be used in mitigating climate change.

The dry matter accumulation by *Chusquea culeou* (Chile) is in the range of 156-162 t/ha. In comparison, that of Phyllostachys pubescens (Japan) and Gigantochloa atter (Indonesia) is 138 t/ha and 45 t/ha, respectively. The lowest dry matter accumulation (0.35t/ha) has been reported in Bashania *fangiana* (China), In *Bambusa bamboos* the dry matter accumulation at the age of 4, 6 and 8 has been reported to be 122, 225 and 286 t/ha, respectively and it is on par with the 10 year old fast growing *Causarina equisetifolia* (292.68 t/ha) or *Eucalyptustereticornis* plantation (254.97 t/ha). The per hectare biomass accumulation by the *D.strictus* at the age of three years is very high compared to that of *Tectona grandis, Dalbergia sisoo, Greveillea robusta,* or *Acacia nilotica* of ten years of age. The above- and below-ground biomass of bamboo is approximately in the ratio of 3:1, and it is observed that the total carbon content usually comprises about 50% of the total biomass.

It was therefore concluded that Bamboo is capable of mitigating climate change through Sustainable management and harvesting practices of bamboo plantations and natural bamboo forests. Bamboo can serve as a reasonable carbon sink.

Keywords: Bamboo, carbon sink, sequestration, forest, and climate change

INTRODUCTION

Today, there is both physical and scientific evidence that the world's climate is changing. Evidence includes a global rise in sea level, increasing desertification, the drying of water resources (rivers and lakes), and an increase in ambient and soil temperatures, as well as changing climatic seasons (Adeoye, 2009). Concentration of greenhouse gases is increasing,

stratospheric ozone is being depleted, and the changing chemical composition of the atmosphere is reducing its ability to cleanse itself through oxidation (Klanderker, 2000). This global change is threatening the balance of climatic conditions under which life has evolved and is sustained

Climate change, primarily caused by human activities since the Industrial Revolution, including the use of fossil fuels, cement production, deforestation, and unsustainable agricultural practices, has doubled the amount of greenhouse gases (GHG) in the atmosphere. A global scientific consensus confirms that the effects of these heat-trapping gases have already caused the global temperature to rise by 0.5 °C, and that, if the current development trend continues, the temperature will increase by 1.4 °C to 5.8 °C by 2100. Scientists agreed that the rising concentrations of anthropogenically produced greenhouse gases in the Earth's atmosphere are responsible for climate change. The greenhouse gases include carbon dioxide, methane (CH_4), and Nitrous Oxide (N2O) from agriculture, as well as "trace gases" or artificial chemicals, including hydrocarbons and sulphur hexafluoride (IPCC, 2001). Ojo *et al.* (2009) stated that the cement industry accounts for 5% of global artificial CO2 emissions, with 50% attributed to the chemical process and 40% to fuel combustion.

Until the Industrial Revolution, the exchanges between atmospheric carbon, the carbon in trees, and on land were in equilibrium. Now, however, the concentration of carbon dioxide in the atmosphere is higher than it has been for at least 365,000 years, although half of the carbon dioxide has been produced in the past 200 years. However, developing countries are fast becoming primary sources of emissions and will soon be the largest absolute source (ADB, 2008). For instance, India, Indonesia, and China ranked among the top ten emitting countries globally due to the combined extent of fossil fuel consumption and deforestation (International Atomic Energy Agency, 2007). Although Africa contributes the least to global emissions of greenhouse gases (GHGs), it is the most vulnerable due to its dependence on rainfed agriculture, widespread poverty, and weak capacity (Nuga, 2008). Consequently, the cumulative impact of climate change over the next two or three decades has the potential to reverse some of the progress made towards attaining the Millennium Development Goals, now known as the Sustainable Development Goals (Stern, 2007).

Due to the above, climate change has become one of the most hotly debated issues in contemporary times. Given the increasing effects of climate change on both human and material resources, it is rapidly dictating economic, production, and consumption activities in different countries, including international trade. As a result, responding to climate change requires fundamental restructuring across key sectors, most notably industry, agriculture, forestry, and transportation. While the impacts of climate change on the ecosystems such as distorted rainfall patterns have been studied, preparation to tackle these impacts both at national and state levels seem to lack vision and are generally based upon the same paradigm of unsustainable development that has brought world to the current state of crises (Sreedhar, 2009).

Given the importance of climate change to the sustainability of the present global alliance, efforts are being made at the global level to provide avenues through joint actions to reduce its effects globally. This paper examines the impact of climate change on sustainable development and highlights climate change mitigation and adaptation options for developing countries, such as Nigeria, through the management of bamboo resources.

Impact of Climate Change on Sustainable Development

Climate change is affecting all phases of human well-being and development. Its adverse impact is expected to increase on the environment, human health, food security, economic activities, natural resources, and physical infrastructure. Some of the feasible evidence of climate change on

sustainable development is enumerated as follows:

Change in Ecological Zones

Climate change has led to a shift in the boundaries of major ecological zones. Studies have shown that variations in climatic parameters, such as precipitation and temperature, influence the observed pattern of biomass distribution (Hanse *et al.*, 2001). It has also been shown that there will be a shift in the areas occupied by forest biomass (Neilson *et al.*, 1999). It has been estimated that globally, the area occupied by tropical and temperate forests will expand by up to 20%, while boreal forests may decline by 50% (Noss, 2001). The current flooding, desertification, and aggravated soil erosion experienced in parts of Africa are attributed to climate change. In the African drylands, which are home to approximately 320 million people, climate change is threatening to exacerbate existing land degradation problems and increase the vulnerability of dryland inhabitants (UNDP/UNCCD/UNEP, 2009). In recent years, approximately 25% of Africa's fragile drylands have been degraded through a process known as desertification (UNEP, 2004).

Reduction in Biodiversity

Biological diversity, also known as biodiversity, refers to the variability among living organisms from all sources, including terrestrial, marine, and other aquatic ecosystems, as well as the ecological complexes in which they are part (ITTO, 2009). The diversity of nature is the foundation of the world's material wealth, as food crops, raw materials, and genetic inputs for industry, agriculture, and medicine are obtained from it. By reducing freshwater supplies, climate change impacts water resources that sustain biodiversity. In Nigeria, for instance, Gbile et al. (1981) reported that 484 plant species, representing 112 families of the country's 4,600 plant species, are endangered. Also, forest decline and dieback occur along the Atlantic and Pacific coasts (Noss, 2001), while the breeding ranges of some mobile species, such as waterfowl, have been extending northwards. Both amphibians and birds have shifted their breeding dates by 1–3 weeks earlier since the 1970s, in conformity with increasing temperatures (Beebee, 1995). Climate change has major impacts on the distribution and abundance of forest-dwelling species, the nature of pests and diseases, and the risks posed by invasive species and fire (ITTO, 2009).

Food Insecurity

The IPCC (2007) reported that the African region is the most vulnerable among the world's regions to the impact of climate change. The most significant and pressing threat of climate change in this region is food insecurity, particularly in the African Drylands. According to the African Union Commission (AUC) Food Security Report, 27% of the total population in Africa is undernourished, nearly half of the children suffer from stunting, and acute malnutrition is observed in more than 15 countries (UNDP/UNCCD/UNEP, 2009). Although there is considerable variability and uncertainty in current climate change projections, there is now reasonable agreement from several different models including the IPCC's Fourth Assessment Report (AR4) on climate change that Africa is at the highest risk from climate change, given the magnitude of existing stresses in the continent (IPCC, 2007). The AR4 estimated that by 2020, between 75 and 250 million people would likely be exposed to increased water stress. That rain-fed agricultural yields could be reduced by up to 50% in some African countries if production remained unchanged (IPCC, 2007). These changes will place additional pressure on already overstretched food supply systems in African drylands, further undermining the livelihoods of pastoralists.

Health Implication

Climate change is one of the defining challenges of the century, and it is increasingly being recognised as a public health priority. Climate change will profoundly affect population health in adverse ways, with negative implications for achieving the health-related Millennium Development Goals. Extreme air temperatures

and air pollution pose significant health hazards. Heat waves are direct contributors to death from cardiovascular and respiratory diseases. High temperatures can also raise the levels of ozone and other air pollutants, which exacerbate cardiovascular and respiratory diseases, as well as pollen and other aeroallergens that trigger asthma. Thus, climate change brings new challenges to the control of infectious diseases. Many of the major killer diseases transmitted by water, contaminated food, and insect vectors are highly sensitive to climate conditions and extreme weather. Consequently, climate change threatens to slow, halt, or reverse current progress against many of these infections (WHO, 2009). An increase in sea surface temperature stimulates the growth of algae, and this has been correlated with outbreaks of cholera (Colwell, 1996). Heavy rainfall, caused by climate change, may also lead to an outbreak of cryptosporidiosis, which can cause severe diarrhea in children and be fatal in immune-compromised individuals (WHO, 2003). In all, the World Health Organisation has reported that an estimated 150,000 deaths occur annually as a result of climate change (FAO, 2006). Since 2008, malaria has been discovered in Papua New Guinea, where it is always too cold for disease-spreading mosquitoes (FAO, 2008).

Threat to Water Resources

The impact of climate change on water availability, distribution, and sustainability has been reported (Aerts, 2009). Climate change has impacted key sources of water, such as monsoons and glaciers (Mahapatra, 2009). One of the most significant fallouts of the warming has been marked changes in rainfall patterns. In Nigeria, rainfall intensity has increased significantly, leading to flooding in both the northern and southern regions of the country. In India, rainfall has increased by 10–12% above normal in the west coast, northern Andhra Pradesh, and north-west India, while the number of rainy days is decreasing by one day every five years in Western Orissa and Central India (Mahapatra, 2009). It causes imbalance and disasters such as floods in Mumbai and droughts in parts of India. In addition, glaciers are melting at an alarming level, with expected changes in mountain ecology. The rivers that obtain their feed from the glaciers in the Himalayas are projected to flood constantly, with rock avalanches likely to occur from destabilised slopes. These are expected to influence water availability within the next three or four decades. According to Oxfam (2005), in less than 30 years, the melting glaciers in the Himalayan regions, which supply up to 85% of the water during the dry season, may affect an estimated population of about 750 million people due to a reduction in water volume. Melting snow is also creating new lakes, many of which have been identified as too dangerous, as their bursting will cause flood damage downstream. Studies have shown that the frequency of glacier lake outburst floods (GLOF) in the Himalayas has risen during the second half of the 20th century (Mahapatra, 2009).

Bamboo and Climate change mitigation

According to the IPCC (2007), emissions must be stabilised between 450 parts per million (ppm) and 550 ppm to avoid dangerous climate change effects globally. To achieve this, the emissions of developed countries need to deviate below projected baselines within the next few decades (IPCC, 2007). Developing countries are under pressure to commit to nationally appropriate mitigation actions (NAMAs). They must also increase efforts to reduce greenhouse gas emissions by investing in cleaner and more efficient infrastructure.

Bamboo has considerable potential to address the problems and hardships associated with climate change. Bamboo can sequester more carbon if managed than if left in its natural state, and can sequester more than comparable fast-growing tropical and sub-tropical trees (INBAR, 2010). The longer life spans of modern bamboo products will help ensure that sequestered carbon does not return to the atmosphere. Bamboo's potential contribution to mitigation relies on the fact that it combines continued biomass production with annual extraction - a significant portion of the culm biomass is extracted every year, while leaving the standing carbon stock relatively

unchanged. Increasing the cultivation and use of bamboo will help improve the resilience of rural and some urban populations to events brought on by climate change, such as extreme weather. Bamboo is easy to grow and maintain, and can provide additional food, energy, and income security to the rural poor, as well as a range of environmental services and uses in its growing and harvested forms.

Within the range of options available to mitigate high levels of carbon dioxide in the atmosphere, forests and forestry practices have garnered considerable attention. While global deforestation is one of the most significant sources of carbon emissions, it is considered relatively easy to halt compared to other options. Through forestry practices, including the expansion of forest area and improvements in forest management, forests can act as important carbon sinks. Although botanically, bamboo is a woody grass and not a tree, bamboo forests share comparable features with other types of forests in terms of their role in the carbon cycle. They sequester carbon through photosynthesis, locking it in the fibres of the bamboo and in the soil where it grows. However, there are also significant differences between bamboo forests and other types of forests. Bamboo exhibits a rapid rate of early growth and high annual regrowth when properly managed. The lifecycle of individual bamboo culms (between 5 and 10 years) is comparatively short. The products derived from bamboo are commonly used in applications with lower durability than those from timber forests.

Bamboo's ability to sequester carbon at high rates, due to its rapid growth, has long been a key part of its green credentials. However, given the complexities of establishing models for vegetative sinks, several questions remain regarding bamboo's ability to sequester and store carbon over different time horizons. Among the complications of quantifying carbon sequestration, there are essential questions regarding bamboo's comparative advantage when compared to other fast growing trees, the length of time over which it sequesters carbon at higher rates than competing species, the role of a bamboo ecosystem in acting as a carbon store, the role that management of bamboo plays in its performance, and the durability of bamboo-derived products (MEA, 2005).

Bamboo can help reduce our carbon footprint and contribute to combating global warming. It is a crucial element in the balance of oxygen and carbon dioxide in the atmosphere (Liebman and Einav, 2009). Bamboo offers a wide range of potential solutions to address the problems and hardships that may arise from climate change (Yiping et al., 2010). Bamboo generates plenty of oxygen, lowers light intensity, protects against UV irradiation, and is an atmospheric and soil purifier. This important grass can also be integrated into land-use-based climate change mitigation activities, such as afforestation, reforestation, or avoided deforestation, as reported by INBAR (2012). Bamboos are among the fastest-growing plants in the world. Studies have shown that appropriately managed and regularly harvested bamboo stands can sequester more carbon than those left in their natural state, and can sequester more carbon than fast-growing tropical and subtropical trees under comparable conditions (INBAR, 2012).

Enhanced protection and management of natural ecosystems, as well as more sustainable management of natural resources and crops, can play a critical role in climate change adaptation strategies (World Bank, 2010).

The green economy and bamboo

Bamboos are woody grasses that grow in the tropical, subtropical, and temperate regions of the world. They occupy over 3% of the world's forests and provide incomes, subsistence, or life goods for an estimated one billion people (INBAR, 2010). Bamboos are often referred to as the fastest-growing plants on the planet, with the potential to help mitigate climate change.

Recent research and growth modelling by the International Network for Bamboo and Rattan (INBAR) has shown that managed bamboo can be

an effective carbon sink and performs better than Chinese Fir and Eucalyptus growing under similar conditions. Managing bamboo involves the annual, sustainable, and selective harvesting of stems, which are then turned into products that can store carbon for many years. The increasing popularity of durable bamboo products ensures that, for the foreseeable future, productive bamboo systems can be considered a carbon sink.

Bamboo's potential contribution to mitigation relies on the fact that it combines continued biomass production with annual extraction - a significant portion of the culm biomass is extracted every year, while leaving the standing carbon stock relatively unchanged. Increasing the cultivation and use of bamboo will help improve the resilience of rural and some urban populations to events brought on by climate change, such as extreme weather. Bamboo is easy to grow and maintain, and can provide additional food, energy, and income security to the rural poor, as well as a range of environmental services and uses in its growing and harvested forms. Although we are aware of many of the ways that bamboo can benefit, further research is needed to fully quantify, understand, and develop the potential that bamboo offers, particularly for the millions of people living in areas considered vulnerable to the effects of climate change.

Carbon storage in bamboo products

As with tree plantations, the bamboo forest system can only be considered a sink if the pool of derived products is growing and if they store carbon for a considerable length of time. While, until recently, most of the bamboo was used for low-value, short-lived products, an increasing amount is now being used for high-value, long-life products, such as boards, which have life expectancies of several decades.

Permanence and leakage of bamboo products are determined on a case-by-case basis but are not expected to differ significantly from timber-wood products. Different processing methods are used for bamboo and wood, but their energy intensities are roughly equivalent.

Carbon sequestration potential of bamboo plantations and Carbon trading

Bamboo has several advantages over tree species in terms of sustainability and carbon fixing capacity (Kumar *et al.,* 1999). Bamboo is one of the most productive and fastest-growing plants on the planet (INBAR, 2006). The fastest-growing species among the bamboos may grow up to 1.2 m a day. This unique growing capacity makes bamboo a valuable sink for carbon storage (INBAR 2010). The dry matter accumulation by *Chusquea culeou* (Chile) is in the tune of 156-162t/ha (Veblen *et al*., 1980), while that of *Phyllostachys pubescence* (Japan) (Isagi *et al.,* 1997), and *Gigantochloa alter* (Indonesia) is 138t/ha and 45t/ha, respectively. The lowest dry matter accumulation (0.35 t/ha) has been reported for Bashania fangiana (China) (Zhou *et al.,* 1997). In our common thorny bamboo, *Bambusa bamboos* the dry matter accumulation at the age of 4, 6 and 8 has been reported to be 122, 225 and 286 t/ha, respectively and it is on par with the 10 year old fast growing *Causarina equisetifolia* (292.68 t/ha) or *Eucalyptustereticornis* plantation (254.97 t/ha). The per hectare biomass accumulation by the *D.strictus* at the age of three years (Singh *et al.* 2004) is very high compared to that of *Tectona grandis, Dalbergia sisoo, Greveillea robusta,* or *Acacia nilotica* of ten years of age. The above- and below-ground biomass of bamboo is approximately in the ratio of 3:1, and it is observed that the total carbon content usually comprises about 50% of the total biomass. Unlike other woody crops, bamboo offers the possibility of annual selective harvesting, and its removal usually does not damage the total stock or the environment. Over the last two decades, bamboo has emerged as a valuable wood substitute, and the carbon captured by bamboo is sequestered effectively for a long time. The degree to which carbon is sequestrated in these products depends on its durability. Over 90% of bamboo carbon can be sequestered in durable products, including boards, panels, floors, furniture, buildings, cloth, paper, and activated charcoal. The decay-resistant

litter produced by bamboo also helps sequester carbon, although its contribution is negligible.

Bamboo plantations can play a significant role in 'carbon trading' in developing countries like Nigeria. "Carbon trading," also known as "cap and trade," is a method developed to reduce carbon emissions that contribute to global warming. Under this arrangement, countries with excess emissions credits can sell them to countries that struggle to reduce their emissions. Reforestation and afforestation projects are part of the Kyoto Protocol's Clean Development Mechanism (CDM), which enables developed countries to meet their targets for reducing greenhouse gas emissions by investing in reforestation and afforestation projects in developing countries, in exchange for carbon credits. Bamboo plantations have the immense potential for such carbon credits. Bamboo plantations, which are significant carbon sinks, have a distinct advantage over other biomass resources due to their species diversity, vigorous growth, early establishment, adaptability to various soil and climatic conditions, short harvesting period, sustainability in yield, and multifaceted uses (over 5,000 applications). Hence, it may be regarded as the most valuable among biomass resources. The species' diversity allows it to occur in any part of the world (except the poles) and to tolerate the climatic exigencies. Bamboo plantations are found to be suitable for clear-felled forest lands, degraded lands, boundaries of agricultural and non-agricultural lands, and other common property resources, such as coastal areas, roadside, canal banks, and railway lines. It has immense potential as a bio-energy resource, which helps retain the carbon already sequestered in fossil fuels such as coal, oil, and gas, and can help save vast natural forests.

Optimal Climate Change Mitigation and Adaptation Strategies for Developing Countries

Adaptation focuses on mitigating the negative effects of climate change by modifying systems to account for new or anticipated conditions. It implies preparing for changes that are now inevitable and may increase further if the GHG emissions are not reduced. Mitigation, on the other hand, refers to the elimination or reduction of the frequency, magnitude, or severity of exposure to environmental, economic, legal, or social risks, or the minimization of the potential impact of a threat or warning. In general, adaptation encompasses measures that mitigate the impact of climate change at local and regional levels, whereas mitigation has a global focus. Among the predominant mitigation measures will be afforestation and reforestation programs, particularly through the management of bamboo resources.

It has been estimated that in Nigeria, between 89,297 and 133,944 km² of arable land could be at risk, which would require an estimated capital value of about US$6.4 billion at the current level of development (NCCC, 2003). In addition, the impending threat of climate change may lead to the disappearance of the long, fully populated coastline in the southern part of the country. A further implication of climate change in Nigeria is that large-scale population displacement is expected, and agricultural and fishing communities will be threatened. Currently, two-thirds of Nigeria is vulnerable to drought and desertification, and approximately 140 million Nigerians depend on the land for their survival (FME, 2009). In addition, Nigeria's development is currently climate-constrained, as the country is heavily dependent on petroleum. It may likely be a hindrance to development based on the proposed global industrialization strategy for emission reduction.

As the country is a signatory to the Kyoto Protocol, Nigeria is required to reduce its overall GHG emissions by 5.2% below the 1990 levels by 2012 (Obot, 2008). Consequently, significant efforts are required through investment in projects that will lead to a reduction in greenhouse gas emissions and adaptation to climate change. It can be sponsored through internally generated revenues and the Clean Development Mechanism (CDM) initiative. Given this, the nation needs

adequate adaptation and mitigation strategies that promote sustainable economic and industrial development in the post-oil-dependent era. Some of the strategies that may be adopted are subsequently discussed.

Resource Management Adaptation Strategies

Forest adaptation to future environmental or social conditions resulting from climate change may significantly alter how and why forestry is practised in many parts of the globe. Anthropogenic warming has already led to numerous changes in forests. IPCC (2007) rated boreal, mountain, Mediterranean, mangrove, and tropical moist forests as the forest ecosystems most likely to be affected by climate change. Forests also influence climate change as sinks for carbon when they grow or expand and sources of greenhouse gases when they are destroyed. The Bali Action Plan, adopted by the 13th Conference of the Parties to the United Nations Framework Convention on Climate Change in 2007, aims to consider forests in developing countries as a prime tool for climate change mitigation. Activities currently addressed include reducing emissions from deforestation and forest degradation in developing countries (REDD) and conservation and enhancement of carbon stocks through sustainable forest management. Locally, forest management and silvicultural practices are likely to influence carbon sequestration by trees, the reaction of forests to climate change, and forest services provided to local populations. Water shortages, unpredictable rainfall, and continued population growth, combined with land degradation, will increase pressure on forest ecosystems and their capacity to meet immediate livelihood needs. As a result, the promotion of community forestry may increase local adaptive capacity by placing decisions in the hands of individuals who are directly affected by climate change and by enhancing the role of traditional knowledge in forest management (Gyampoh *et al.*, 2009).

There are three (3) possible approaches for adapting forests to climate change. These include no intervention, reactive adaptation, and planned adaptation. According to Gyampoh *et al.* (2009), planned adaptation involves redefining forestry goals and practices in advance, taking into account the risks and uncertainties associated with climate change. It involves deliberately anticipating interventions at different levels and across sectors. At the community level, this may include diversification of forest-based and non-forest-based income sources, better local governance of forest resources, and capacity building for monitoring and coping with possible calamities of unprecedented extent. At the national and global levels, planned adaptation may include the development of timely monitoring and reporting systems, as well as tools for vulnerability assessment and adaptation planning. Planned adaptation also includes exploring new opportunities that may arise as a result of climate change. For example, planting provenances or species that will grow faster under projected climate conditions, or reaping the benefits of new products and services such as carbon sequestration and new forms of bioenergy. Planned adaptation may reduce vulnerability and increase resilience. It may entail diversification at the expense of productivity. At the stand level, it may mean planting a larger diversity of species or provenances, or trees bred for resistance to expected stressors. Modification of thinning schedules may help stabilise stands against drought, storms, and diseases, and may also help capture additional growth from CO2 fertilisation. At the scale of landscapes, planned adaptation may include measures to minimise the potential impacts of fire, insects, and diseases, as well as increased afforestation and reforestation, the creation of biodiversity corridors, and the rehabilitation of degraded forests.

It is becoming increasingly important that forest management plans incorporate uncertainty and the increased probability of extreme events, as well as periodic comparisons of projections against evolving reality to update targets and methods. Intensive forest monitoring is also a sine qua non for successful adaptation plans. In developing

countries like Nigeria, a lack of funding and expertise for monitoring and assessment may hinder the early detection of climate change impacts and responses. Consequently, planned adaptation must start with capacity building for periodic forest assessments.

Sustainable forest management principles, if adopted, are capable of controlling indiscriminate forest exploitation and illegal logging. Sustainably managed forests can adapt more effectively to climate change, and sustainable management can help reduce or reverse forest loss and degradation, thereby enhancing forest resilience to climate change. In Nigeria, REDD can serve as a measure of adaptation by capitalising on opportunities created by climate change, such as incentive payments, carbon sales, and investments in forests.

CONCLUSION

Sustainable management and harvesting practices are crucial for bamboo plantations and natural bamboo forests to utilise and maintain their capacity for carbon sequestration effectively. If not adequately managed or left unmanaged, the quantity of carbon sequestered in Moso bamboo was calculated to be only about 30% of that in Chinese for over a 30-year period in subtropical regions. Thus, to achieve higher levels of carbon sequestration, sustainable bamboo management, regular harvesting, and utilization for durable products should be advocated.

However, the bamboo planted to help reduce global warming will also clean the air, filter stormwater, lower energy bills, and provide habitat for local wildlife. Based on the United Nations Framework Convention on Climate Change (UNFCCC) and the Kyoto Protocol, which recognise the importance of forests in mitigating climate change, there are general obligations regarding forests that are listed. It is based on the obligation that the following recommendations are made: promote sustainable (Bamboo) forest management, promote and cooperate in the conservation and enhancement of bamboo forests as sinks and reservoirs of greenhouse gases. Also promote afforestation and reforestation, as well as the development of renewable energy sources. Bamboo forestss should be considered as part of national inventories of greenhouse gas emissions removals, in technology transfer, and national programmes of mitigation to climate change.

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ASSESSMENT OF GROWTH YIELD IN RELATION TO NUTRIENT STATUS ON *Eucalyptus cameldulensis* IN TUDUN-IYA PLANTATION, KATSINA STATE, NIGERIA

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Abstract

The study assessed the growth yield in relation to nutrient status in Eucalyptus camaldulensis stands established in Tudun-Iya plantation, which were established in 1974, 1976, and 1978. Simple random sampling was employed, with eight plots of 20 m x 20 m each for each plantation, totaling 24 plots. Soil samples were collected from two depths (0-30 and 30-60 cm) from six plots (two in each age group). Growth tree variables measured include the number of stems, tree height, and diameter at breast height, at base, at middle, and at top. Basal area and volume were calculated and subjected to a Pearson Correlation Coefficient Analysis. The results show that the total stem per hectare are 10950/ha, 11050/ha and 12050/ha for the 1978, 1976, 1974 years' stand respectively, while the basal area per hectare are 6863.028, 8342.178 and 6545.496 m^2/ha for 47, 49 and 51 years respectively and the volume per hectare recorded for the year 1978, 1976 and 1974 are 28921.63, 30945.71 and 164054.52 m^3/ha respectively. The results provide valuable insights into the soil physical and chemical properties of the study area and are in good shape. The soil's physical and chemical properties significantly correlated with growth variables.

Key Words: Soil Depth, Plantations, Stand Age, Growth Variables, Correlation, Properties

1. Introduction

Forest plantations are forest ecosystems where the majority of trees have been intentionally established through planting and/or seeding. While this definition may seem straightforward, it encompasses a diverse range of forest types, from monocultures of non-native species to mature forests that resemble natural formations. Many planted forests, especially those that have matured over time, can be indistinguishable from natural forests. The geometric shapes and uniform tree spacing that characterize young plantations often give way to a more natural, heterogeneous appearance as the forest ages. Examples of Planted Forests with a Natural Appearance: Some of the oldest and most famous forests in Europe, such as the New Forest in England or the Fontainebleau Forest in France, appear entirely natural despite being planted centuries ago. These forests have undergone significant changes over time, including the introduction of native species and the development of complex forest structures (Haggar *et al.,* 2017).

Plantation forestry is increasingly based on the successive rotation of plantations or the establishment of new forests on degraded land (Weiskittel *et al*., 2011). This approach distinguishes plantation forests from native forests, which are natural assets with inherent ecological value. In contrast, plantation forests are deliberately grown, often referred to as tree farms, for specific purposes such as timber production, carbon sequestration, or provision of ecosystem services (CIFOR, 2019).

Plantation forestry in Nigeria involves the establishment and management of tree plantations for various purposes, including timber production, pulpwood, and non-timber forest products. Nigeria has a long history of plantation forestry, dating back to the colonial era (Federal Ministry of Environment, 2019). The British colonial authorities established the first tree plantations in Nigeria in the early 20th century. The plantations were primarily focused on producing timber for export (FAO, 2020). After Nigeria gained independence in 1960, the government continued to support plantation forestry, establishing new

plantations and expanding existing ones. Today, Nigeria has a significant plantation forestry sector, with plantations covering over 1 million hectares of land. The majority of plantations are owned and managed by the government, while private companies and individuals own a portion of them. Nigerian Conservation Foundation (NCF, 2020).

Sustainable land use requires careful management of soil nutrients to maintain ecosystem health and productivity (Lal, 2015). However, intensive land use practices, such as biomass production, can lead to nutrient depletion and soil degradation (Smith, 2016). To remedy nutrient loss, supplements such as inorganic fertilizers are often necessary. While these supplements can help maintain soil fertility, they can also increase the input costs of forest management. In turn, it can affect the economic viability of biomass production as a renewable energy source (Weih, 2017).

Soils under many plantations are prone to nutrient leaching due to rapid litter decomposition and heavy rainfall events. It can lead to nutrient-poor soils, particularly in phosphorus and potassium. Forest floor litter serves as a reservoir for carbohydrate energy and inorganic nutrients. These organic materials can be manipulated to optimize nutrient cycling and energy distribution (Richardson *et al.,* 2020). However, the pattern of nutrient and energy distribution varies significantly with tree species and site conditions. When allowed to decompose naturally, most nutrients in forest floor litter are returned to the soil and living vegetation. This process incorporates organic matter into the mineral soil, enhancing its capacity to retain water, oxygen, and nutrients (Zhang *et al.,* 2022). The incorporation of organic matter into mineral soil has several benefits, including Improved soil structure. Organic matter helps aggregate soil particles, thereby enhancing soil porosity and water infiltration. Enhanced nutrient retention: Organic matter acts as a nutrient reservoir, slowly releasing nutrients as needed by plants. Additionally, organic matter serves as a food source for soil microorganisms, thereby promoting a diverse and active soil biota (Wang *et al.,* 2022).

2.0 Materials and Methods

2.1 Study area

The study area is located between Latitudes 11°12′ N and 1300 N and Longitudes 7°09′ E and 90 ° E in Tudun-iya village, Funtua Local Government Area, Katsina State. The study site experiences a tropical continental climate characterized by distinct wet and dry seasons. The vegetation type of the study site is the West African type, which follows the pattern of rainfall distribution and falls within the Sudan Savanna zone of Nigeria. Trees and shrubs include: *Acacia nilotica*, *A. polyacantha*, *Adansonia digitata, Balanites aegyptiaca, Parkia bioglobosa, Guiera senegalensis, Diospyros mesipiliformis, Ficus syncomorus, Borassus aethoipium, Vitex doniana, Vitellaria paradoxa,* and *Khaya senegalensis*. While sorghum, maize, millet, and other crops are cultivated, the dominant grass species are *Andropogoneae,* especially the genera *Andropogon* and *Hyparrhenia*.

2.2 Methods

A preliminary survey was conducted at the study site to gather general information about the plantation. Subsequently, the reconnaissance survey covered the entire plantation to gain an overall impression, planned the methodology, and addressed potential challenges that might arise during the research. Three age sequences were selected in the plantation: 1974, 1976, and 1978 (51, 49, and 47 years of age, respectively).

2.3 Data Collection

Eight (8) temporary sample plots of 20 x 20 m were laid at each age sequence, making 24 sample plots. Diameter at breast height DBH (cm) and total tree height (HT), total number of trees, diameter at the base, middle, and the top. The total height of the four largest trees per plot served as the dominant trees. Samples of soil were collected randomly at both surface and sub-surface (0-30 cm and 30-60 cm, respectively) from the sample plots of each sequence using a Hand Auger. The soil samples collected were taken to the laboratory for analysis. The tools used in this research include a compass, a machete, tally sheets, an axe, a Global Positioning System (GPS), a diameter tape, a Haga Altimeter, a linear tape, a Spiegel-Relaskope, a scientific calculator, a work map, and stationery.

2.3.1 Statistical Analysis

Both descriptive and inferential statistics were employed in the analysis of this study, using the Statistical Package for the Social Sciences (SPSS, Version 25), a 34-bit edition produced by IBM.

2.3.2 Data Analysis

The data collected from the field was processed into the following:

2.3.3 Basal area

$BA = \frac{\pi D^2}{4}$ Equation 1; Where; BA = individual tree basal area (m), D = diameter at breast height (cm), π = constant (3.142)

2.3.4 Basal Area/ha

Plot basal area was obtained by summing up all individual tree basal areas and dividing by the number of plots. $B_p = \frac{\sum b_i}{n}$ Equation 2: Where B_p = plot basal area, n = number of trees, and b_i individual basal area.

2.3.5 Volume Estimation

The volume of the species was calculated using Newton's formula.

$v = \left(\frac{A_b + 4Am + A_t}{6}\right) H$ Equation 3; Where; V = Volume, H = Tree height, Ab= Cross sectional area at the base, Am= Cross sectional area at the middle and At = Cross sectional area at top. While the cross-sectional area is $\pi \left(\frac{DBH}{2}\right)^2$ Equation 4: Where DBH is Diameter at breast height (cm) and π is constant (3.142).

3.0 Results

3.1 Growth Variables for *Eucalyptus camaldulensis* of the study area

A study was conducted to investigate the relationship between soil nutrients and growth variables of *Eucalyptus camaldulensis* in Tudun-Iya plantations of 47, 49, and 51 years old, corresponding to the years 1978, 1976, and 1974, respectively. Stand density, the number of stems per hectare, was found to be 10950/ha, 11050/ha, and 12050/ha for the 1978, 1976, and 1974 stands, respectively. The mean diameter at breast height was significantly higher in 1976 (93.42 cm) and lowest in 1974 (79.01 cm). The mean height was highest in 1976 (14.85 m) and lowest in 1974 (14.32 m). The mean dominant height was highest in 1974 (27.82m) compared to the least recorded in 1976 (23.68m), with an average dominant height of 26.45m in 1978. The total Basal area per hectare for the three (3) age series was found to be 6863.028, 8342.178 and 6545.496 m^2/ha for 47, 49 and 51 years respectively and the year 1976 recorded the highest basal area per hectare (8342.178 m^2/ha), while the year 1974 has the lowest Ba/ha (6545.496 m^2/ha). The results of the study showed that 28,921.63, 30,945.71, and 164,054.52 m^3/ha were the volumes per hectare recorded for the years 1978, 1976, and 1974, respectively. These results provide valuable insights into the growth patterns of *Eucalyptus camaldulensis* in the study area.

Table 1. **Growth Variables for *Eucalyptus camaldulensis* of the study area**

AGE	Tree	Stem/ha	M.HT	M.DHT	M.DBH	BA/ha	M.BA/ha	Vol./ha	M.Vol/ha
1978	438	10950	14.55	26.45	85.81	6863.028	16.11	12416680	28921.63
1976	442	11050	14.85	23.68	93.42	8342.178	18.67	13842256	30945.71
1974	482	12050	14.32	27.82	79.01	6545.496	13.58	67899450	164054.52
TOTAL	**1362**	**34050**	**43.72**	**77.95**	**258.24**	**21750.7**	**48.36**	**94158386**	**223921.9**

3.2 The Soil Chemical Properties in the Study Area

The summary of soil chemical properties in the study area at 0 - 30 cm and 30 - 60 cm depth for the three ages accordingly are: the potential of hydrogen (pH 1:2) are 6.41, 5.7 and 6.14 at surface and 5.6, 5.7 and 6.7 at sub-surface for 1978, 1976 and 1974 respectively. The pH values ranged from 5.6 to 6.7, indicating a slightly acidic to neutral soil pH. The pH values at the 0-30 cm depth were higher than those at the 30-60 cm depth, suggesting a decrease in pH with increasing depth. Electrical Conductivity (EC) at (0-30 cm) for the three age series are 0.064, 0.05, and 0.063 while at sub-surface (30-60 cm) are 0.043, 0.104, and 0.048 respectively. The EC values ranged from 0.043

to 0.104 ds/m, indicating a relatively low to moderate soil salinity. The EC values at 0-30 cm depth were higher than those at 30-60 cm depth, suggesting a decrease in EC with increasing depth. Organic Carbon (CO), the percentage of organic carbon in the soil of the study area is 1.337, 1.207, and 1.2369 for the surface (0 - 30 cm) and 0.948, 1.327, and 1.117 for sub-surface (30 – 60 cm) for the 1978, 1976, and 1974, respectively. The OC values ranged from 0.948 to 1.337%, indicating a moderate to high soil organic matter content. The OC values at depths of 0-30 cm were higher than those at 30-60 cm, suggesting a decrease in OC with increasing depth.

Available Nitrogen (Av-N%). The percentage of AvN in the soil sample for (0 – 30 cm) depth is 0.0025, 0.0014, and 0.0017, while (30 – 60 cm) depth is 0.0027, 0.0025, and 0.0007 for the three age series. The Av-N values ranged from 0.0007 to 0.0027%, indicating a relatively low soil nitrogen availability. The Av-N values at 0-30 cm depth were higher than those at 30-60 cm depth, suggesting a decrease in Av-N with increasing depth. Available Phosphorus (Av-P mg/kg). The result of the study showed that plantation 1978 has higher AvP with 10.981 but 1976 has the lowest with 7.400 and 1974 is slightly higher than 1976 with the value of 7.785 in surface of the soil (0 – 30 cm) while in sub-surface 1976 has the highest value of 10.786 and 1978 has the lowest with 7.075 and 1974 recorded 9.509. The Av-P values ranged from 7.075 to 10.981 mg/kg, indicating a moderate to high soil phosphorus availability. The Av-P values at 0-30 cm depth were higher than those at 30-60 cm depth, suggesting a decrease in Av-P with increasing depth. The concentration of Calcium (Ca cmol/kg) in 1978, 1976, and 1974 in the surface layers is 9.60, 4.80, and 5.60, respectively, while in the subsurface layers is 6.40, 1.60, and 5.60. The calcium (Ca) content ranged from 4.80 to 9.60 cmol/kg, indicating a moderate to high level of soil calcium. Magnesium (Mg) cmol/kg is also 3.60, 1.60, and 2.80 for (0-30 cm), while 3.20, 2.00, and 3.60 for (30-60 cm), respectively. The magnesium (Mg) content ranged from 1.60 to 3.60 cmol/kg, indicating a moderate soil magnesium level.

The Sodium (Na cmol/kg) showed that 1978 has 0.57, 1976 has a value of 0.65, and 1974 has 0.26 on (0-30 cm), while it has 0.91, 0.78, and 0.26 on (30-60 cm). The sodium (Na) content ranged from 0.26 to 0.91 cmol/kg, indicating a relatively low soil sodium level. Potassium (K cmol/kg) (0.67, 0.77, and 0.67) on (0-30 cm) and (0.33, 0.72, and 0.13 on (30-60 cm) for the three ages. The potassium (K) content ranged from 0.13 to 0.77 cmol/kg, indicating a relatively low soil potassium level. Total exchangeable base (TEB cmol/kg) values are 4.43, 7.82, and 9.33 on (0-30 cm) and 10.85, 5.10, and 9.59 on (30-60 cm) for 1978, 1976, and 1974, respectively. The total exchangeable base (TEB) content ranged from 4.43 to 10.85 cmol/kg, indicating a moderate to high level of soil base saturation. The Total exchangeable acid (TEA cmol/kg) values recorded are 1.20, 1.20, and 2.40 on (0-30 cm), while 30-60 cm recorded 2.40, 2.00, and 1.20 for the age series. The total exchangeable acid (TEA) content ranged from 1.20 to 2.40 cmol/kg, indicating a relatively low level of soil acid saturation. The Exchangeable cation adequate capacity (ECEC cmol/kg) values are 15.63, 9.02, and 11.73 on (0-30 cm) and 13.25, 11.24, and 10.79 on (30-60 cm).

The ECEC values ranged from 9.02 to 15.63 cmol/kg, indicating a moderate to high soil cation exchange capacity. And phosphorus base saturation (PBS% %), the plantation in 1978 has 92.32 %, and 1976 has 86.70 % and 1974 recorded 79.54 % on (0-30 cm), while the percentages for (30-60 cm) are 81.88, 71.83, and 88.88 % respectively. The phosphorus base saturation (PBS) values ranged from 71.83 to 92.32%, indicating a moderate to high level of phosphorus saturation in the soil exchange complex. The high PBS values suggest that the soil has a high capacity to retain phosphorus, which may be beneficial for plant growth but also potentially leads to phosphorus fixation and reduced availability. The variation in PBS values across different depths and ages may be influenced by factors such as soil type, land use, and fertilization practices. These results provide valuable insights into the soil chemical properties of the study area and can inform soil management decisions to optimize plant growth and ecosystem health.

3.3 The Soil Physical Properties in the Study Area

The results of the soil physical properties indicated a significant difference in the textural classes. In the 1978 plantation, the soil was Sandy clay loam at a depth of 0–30 cm, while there was no significant difference for the 1976 and 1974 plantations, which both recorded Loamy sand. However, there was a significant difference in the subsurface (30-60 cm), where it was recorded as sandy loam in 1978, sandy clay loam in 1976, and sandy in 1974. The percentage of Sand (%) for the three age

series on surface (0 – 30 cm) are 60.00, 84.00, and 83.00, respectively, and for sub-surface (30-60 cm) are 80.00, 74.00, and 89.60, respectively. The percentage (%) of silt on the surface (0 – 30 cm) is 10.60, 5.60, and 7.60 in the plantations of 1978, 1976, and 1974, respectively, while it recorded 3.60, 3.60, and 6.60 in the subsurface (30 - 60 cm), respectively. The percentage (%) for clay show significant difference between the three ages, plantation 1978 has 29.40 (%), while 1976 and 1974 has 10.40 and 9.40 (%) respectively in (0 -30 cm) and in the (30 – 60 cm) has 16.40, 22.40 and 13.80 for the three age series. In bulk density (BD, g/cm³), the surface (0–30) of 1978 has a value of 1.39, while 1976 and 1974 have values of 1.59 and 1.61, respectively. The sub-surface (30 60 cm) recorded the values of 1.52, 1.46, and 1.70, respectively. The particle density (PD, g/cm³) of the three ages is 2.22, 2.58, and 2.50, while in the (30–60 cm) range, it has the values of 2.50, 2.67, and 2.65, respectively. The percentage of Total Porosity (%) for 1978 in surface (0 – 30 cm) has the value of 37.39, the plantations of 1976 and 1974 have the values of 38.37 and 35.60, while in the (30 -60 cm) layer, they have the values of 39.20, 45.32 and 35.85 (%) respectively.

3.4 The Correlation between Tree Growth Variables and Soil Physical Properties

The correlation coefficient value obtained between some of the tree growth variables and soil physical properties in the study area indicates the degree and level of relationship. MDH and Sand (0.54), MDBH and Clay (0.51), MDBH and BD (-0.53). TP and Clay (0.65), Sand and BD (0.92), Sand and Clay (-0.93), PD and TP (0.58), Clay and BD (-0.99), Silt and Sand (-0.46), Sand and TP (-0.581), Clay and Sand (-0.93) all the above-mentioned physical property of soil significantly correlated with growth variables.

Table 2. Correlation between Tree Growth Variables and Soil Physical Properties

	M.HT	M.DHT	M.DBH	BA/ha	Vol/ha	SAND	SILT	CLAY	Bulk density	Particle density	T. Porosity
M.HT	1										
M.DHT	0.64	1.00									
M.DBH	0.34	-0.25	1.00								
BA/ha	0.58	0.01	0.89	1.00							
Vol/ha	0.28	0.22	-0.01	-0.19	1.00						
SAND	0.09	0.10	0.54	0.38	0.13	1.00					
SILT	0.22	0.15	-0.23	-0.08	-0.20	-0.46	1.00				
CLAY	-0.20	-0.17	-0.51	-0.39	-0.06	-0.93	0.10	1.00			
Bulk density	0.17	0.11	-0.53	0.41	0.03	0.92	-0.10	-0.99	1.00		
Particle density	0.18	0.31	0.24	0.29	-0.01	0.23	-0.07	-0.23	0.19	1.00	
T.Porosity	-0.01	0.14	-0.25	-0.12	-0.02	-0.58	0.00	0.65	-0.69	0.58	1

3.5 The Correlation between Tree Growth Variables and Soil Chemical Properties

On the other hand, there was a strong positive correlation coefficient (0.88) between the basal area

and ECEC of soil chemical properties in the study area. Mean diameter at breast height (DBH) and mean dominant height also show a strong positive correlation with TEB (r = 0.88). Basal and mean DBH were strongly positively correlated (r = 0.89). There was a significant negative correlation between mean height and average nitrogen (AvN) (-0.83) and between mean dominant height and average nitrogen (AvN) (-0.50). Likewise, a negative correlation was observed between mean dominant height and magnesium (Mg) (-0.15). Calcium (Ca) and TEB (r = 0.87), calcium and ECEC (r = 0.89), calcium and PBS (r = 0.59), PBS and TEA (r = 0.70), PBS and TEB (r = 0.77), and ECEC and TEB (r = 0.97) are all significantly correlated.

Table 3. Correlation between Tree Growth Variables and Soil Chemical Properties

	M.HT	M.DHT	M.DBH	BA/ha	Vol/ha	Ca	Mg	Na	K	TEB	TEA	ECEC	PBS
M.HT	1												
M.DHT	0.64	1.00											
M.DBH	0.34	-0.25	1.00										
BA/ha	0.58	0.01	0.89	1.00									
Vol/ha	0.28	0.22	-0.01	-0.19	1.00								
Ca	-0.06	-0.46	0.02	-0.03	-0.15	1.00							
Mg	0.10	-0.15	-0.11	0.08	-0.24	0.21	1.00						
Na	-0.24	-0.07	-0.19	-0.35	0.24	-0.33	0.03	1.00					
K	0.07	0.34	-0.66	-0.53	0.41	-0.17	0.16	0.32	1.00				
TEB	-0.02	0.88	-0.12	-0.08	-0.16	0.88	0.63	-0.14	0.06	1.00			
TEA	-0.36	-0.11	0.15	0.02	-0.48	0.00	-0.28	-0.23	-0.34	-0.18	1.00		
ECEC	-0.10	-0.46	-0.08	0.88	-0.28	0.89	0.57	-0.19	-0.01	0.97	0.05	1.00	
PBS	0.34	-0.13	-0.06	0.02	0.31	0.59	0.60	-0.06	0.21	0.77	-0.70	0.62	1.00

	M.HT	M.DHT	M.DBH	BA/ha	Vol/ha	pH	EC	O.C	Av-N	Av-P
M.HT	1.00									
M.DHT	0.64	1.00								
M.DBH	0.34	-0.25	1.00							
BA/ha	0.58	0.01	0.89	1.00						
Vol/ha	0.28	0.22	-0.01	-0.19	1.00					
pH	0.11	-0.08	0.11	0.29	-0.42	1.00				
EC	0.04	0.22	-0.14	0.05	-0.21	-0.15	1.00			
O.C	0.09	0.11	0.03	0.05	0.05	0.17	0.48	1.00		

Av-N	-0.83	-0.50	-0.31	-0.48	-0.26	-0.19	0.03	-0.05	1.00	
Av-P	0.21	0.01	0.00	0.28	-0.33	0.28	0.56	0.18	0.03	1.00

4.0 Discussions

4.1 Growth Variables for *Eucalyptus camaldulensis*

The growth variables of *Eucalyptus camaldulensis* in Tudun-Iya plantations had a higher mean DBH (93.42 cm) and mean height (14.85 m) at 49 years old. These findings are consistent with other studies on the species. For example: A study by Isik (2019) found that *Eucalyptus camaldulensis* plantations in Turkey had a mean DBH of 85.6 cm and a mean height of 13.4 m at 40 years old. Another study by Khamzina *et al.* (2017) found that *Eucalyptus camaldulensis* plantations in Uzbekistan had a mean DBH of 70.3 cm and a mean height of 12.1 m at 30 years old, which is lower than the findings of this study. A review of *Eucalyptus camaldulensis* growth and yield by du Toit (2015) reported that the species can reach a mean DBH of 100 cm and a mean height of 20 m at 50 years old. The findings of this study are generally consistent with these related studies, although the Tudun-Iya plantations appear to have slightly faster growth rates. These differences may be due to factors such as climate, soil type, and management practices.

4.2 The soil chemical properties

The study's results on soil chemical properties showed that the pH value ranged from 5.6 to 6.7, indicating a slightly acidic to neutral soil pH. The pH values at depths of 0-30 cm were higher than those at depths of 30-60 cm. The results of the study are consistent with those of other studies on similar soils. A study reported by Smith et al. (2019) found that the pH of soils in a similar region ranged from 5.5 to 6.5, which is consistent with the findings of this study. Electrical Conductivity (EC) ranged from 0.043 to 0.104 ds/m, indicating a relatively low to moderate soil salinity. EC values at 0-30 cm depth were higher than those at 30-60 cm depth. Organic Carbon (OC); Ranged from 0.948 to 1.337%, indicating a moderate to high soil organic matter content. OC values at 0-30 cm depth were higher than those at 30-60 cm depth. The study is consistent with a study reported by Johnson *et al. (2018), which found that the organic carbon content of soils in a similar ecosystem ranged from 0.8 to 1.4%, a finding similar to those* of this study. Available Nitrogen (Av-N) ranged from 0.0007 to 0.0027%, indicating a relatively low soil nitrogen availability. Av-N values at 0-30 cm depth were higher than those at 30-60 cm depth. Available Phosphorus (Av-P) ranged from 7.075 to 10.981 mg/kg, indicating a moderate to high soil phosphorus availability. Av-P values at 0-30 cm depth were higher than those at 30-60 cm depth. This finding is similar to that of a study by Davis et al. (2017) on a review of soil fertility management practices, which found that the optimal range for available phosphorus in soils is between 5 and 15 mg/kg, consistent with the results of this study. Calcium (Ca), Magnesium (Mg), Sodium (Na), and Potassium (K). Ca: 4.80-9.60 cmol/kg, indicating a moderate to high soil calcium level. Mg: 1.60-3.60 cmol/kg, indicating a moderate soil magnesium level. Na: 0.26-0.91 cmol/kg, indicating a relatively low soil sodium level. K: 0.13-0.77 cmol/kg, indicating a relatively low soil potassium level. Total Exchangeable Base (TEB) and Total Exchangeable Acid (TEA); TEB: 4.43-10.85 cmol/kg, indicating a moderate to high soil base saturation level. TEA: 1.20-2.40 cmol/kg, indicating a relatively low soil acid saturation level. Exchangeable Cation Effective Capacity (ECEC) and Phosphorus Base Saturation (PBS); ECEC: 9.02-15.63 cmol/kg, indicating a moderate to high soil cation exchange capacity. The result of this study is higher than that reported by Lee et al. (2016), who found that the exchangeable cation adequate capacity (ECEC) of soils in a similar region ranged from 5 to 10 cmol/kg. These differences may be attributed to variations in location, soil type, land use, and management practices.

Similarly, the Phosphorus Base Saturation (PBS) of this study ranging from 70 to 90% indicating a moderate to high level of phosphorus saturation in the soil exchange complex, which is higher than the study reported by Kim *et al.,* (2015), that the phosphorus base saturation (PBS) of soils in a similar ecosystem ranged from 50 to 70%. The differences may be due to locations, variations in soil type, land use, and management practices. The findings of this study have implications for soil fertility management and conservation practices. The high pH and ECEC

values suggest that the soil has a high capacity to retain nutrients, but may require additional nutrient inputs to optimise plant growth. The moderate to high OC and Av-P values suggest that the soil has a high potential for plant growth, but may require additional management practices to maintain soil fertility.

4.3 Soil Physical Properties

The texture of the soil varied with depth and age. The surface texture (0-30 cm) was sandy clay loam in 1978, and Loamy sand in 1976 and 1974. The subsurface (30-60 cm) texture was sandy loam in 1978, sandy clay loam in 1976, and sandy in 1974. The study is consistent with other studies on similar soils (Smith et al., 2019). Reported that the texture of soils in a similar region ranged from sandy loam to clay loam, which is consistent with the findings of this study. Sand, Silt, and Clay Content: The percentage of sand ranged from 60% to 89.6%, with the highest value in the subsurface of 1974. There are some differences between the findings of this study and other related studies. Kim *et al.* (2015) reported that the sand content of soils in a similar ecosystem ranged from 40 to 60%, which is lower than the findings of this study. This may be due to location, variations in soil type, land use, and management practices. The percentage of silt ranged from 3.6% to 10.6%, with the highest value at the surface in 1978. The percentage of clay ranged from 9.4% to 29.4%, with the highest value at the surface in 1978.

Bulk Density (BD) and Particle Density (PD). The bulk density ranged from 1.39 to 1.70 g/cm³, with the highest value in the subsurface of 1974. The study is consistent with other studies by Johnson *et al.* (2018). Reported that the bulk density of soils in a similar ecosystem ranged from 1.3 to 1.6 g/cm3, which is similar to the findings of this study. The particle density ranged from 2.22 to 2.67 g/cm³, with the highest value in the subsurface of 1976. The findings of this study are slightly different with other related study, a study reported by Lee *et al.,* (2016), found that the particle density of soils in a similar region ranged from 2.5 to 2.8 g/cm^3, which is higher than the findings of this study, the differences may be due to location, variations in soil type, land use, and management practices. The total porosity ranged from 35.60% to 45.32%, with the highest value in the subsurface of 1976. The study is consistent with a review of soil physical properties by Davis *et al. (2017), which found that the total porosity of soils in a similar region ranged from 30 to 50%, aligning* with the findings of this study. The findings of this study have implications for soil management and plant growth. The variation in texture and soil physical properties with depth and age suggests that soil management practices should be tailored to the specific soil conditions. The high sand content and low clay content in some soils may indicate a need for irrigation management and soil conservation practices. The moderate to high total porosity values suggest that the soils have good aeration and water infiltration properties.

4.4 The Correlation between Tree Growth Variables and Soil Physical Properties

The correlation coefficient values obtained between tree growth variables and soil physical and chemical properties indicate the degree and level of relationship between them. The correlation between Tree Growth Variables and Soil Physical Properties shows that MDBH and Sand were positively correlated (0.54), MDBH and Clay were positively correlated (0.51), MDBH and bulk density were negatively correlated (-0.53), this is similar with a study reported by Sanchez *et al*., (2003), that soil bulk density was negatively correlated with tree growth, while soil porosity was positively correlated. Other significant correlations include: TP and Clay (0.65), Sand and BD (0.92), Sand and Clay (-0.93), PD and TP (0.58), Clay and DB (-0.99), Silt and Sand (-0.46), Sand and TP (-0.58) and Clay and Sand (-0.93). The result of this study is consistent with the study reported by Gregory *et al. (2007), which found that soil texture and structure have* a significant impact on tree root growth and development. Another review study, reported by Binkley et al. (2013) found that soil physical properties, such as bulk density and porosity, were important factors influencing tree growth and productivity.

4.5 Correlation between Tree Growth Variables and Soil Chemical Properties

The Basal area and ECEC were strongly positively correlated (0.88). Mean diameter at breast height (DBH) and mean dominant height were strongly positively correlated with TEB (0.876). Basal

area and mean DBH were strongly positively correlated (0.89). It is consistent with a review study by Liu *et al.* (2020), which found that tree growth variables, such as DBH and height, were significantly correlated with soil chemical properties. Other significant correlations include: Mean height and average nitrogen (AvN) (-0.83), Mean dominant height and average nitrogen (AvN) (-0.50), Mean dominant height and magnesium (Mg) (-0.1547), Calcium (Ca) and TEB (0.87), Calcium and ECEC (0.89), Calcium and PBS (0.59), PBS and TEA (0.70), PBS and TEB (0.77), and ECEC and TEB (0.976). It is consistent with other related findings. For example, a study reported by Prescott et al. (2017) found that soil organic matter content and nutrient cycling were important factors influencing tree growth and productivity. Another study by Laclau et al. (2019) reported that soil chemical properties, such as pH and nutrient availability, were critical factors influencing tree growth and ecosystem health. Wang *et al.* (2020) also reported that tree height was positively correlated with soil nutrient availability and negatively correlated with soil acidity. The correlation analysis highlights the importance of considering both soil physical and chemical properties when evaluating tree growth variables

4.6 Conclusion

The assessment of growth yield about nutrient status on *Eucalyptus camaldulensis in 1974, 1976, and 1978 plantations was carried out. T*he growth performance about some soil physical and chemical properties was examined. The tree growth variables were discovered to increase with age. The relative distribution of soil physical properties supported the growth and development of the species. Soil chemical properties were effective in influencing tree growth performance, but in varying proportions. The tree growth variables are correlated with most of the physical and chemical properties of the soils.

4.7 Recommendations

1. Accurate modeling of forest stand dynamics is essential for predicting future wood yields and planning sustainable harvests.
2. Strengthening forest governance and law enforcement
3. Implementing sustainable forest management plans
4. Promoting community-led forest management and benefit-sharing

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INFLUENCE OF SEED SIZE ON GERMINATION AND EARLY SEEDLING GROWTH OF *GARCINIA KOLA*: IMPLICATIONS FOR CONSERVATION AND SUSTAINABLE USES

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Abstract

Seed germination remains a significant challenge for *Garcinia kola*, a recalcitrant seed species with economic and ecological importance. This study examines the impact of seed size on the germination and early seedling growth of G. kola, offering insights into its conservation. A total of 250 seeds were sourced from Omifon Village, Odigbo Local Government Area, Ondo State. From these, 30 seeds were randomly selected and categorized into three size classes: small, medium, and large, based on their length, thickness, and weight. These were used as replicates and arranged in a completely randomized design. Germination parameters, including germination index (GI), coefficient of velocity of germination (CVG), and mean germination time (MGT), were assessed. Based on Analysis of Variance (ANOVA), the mean length, thickness, and weight of seeds varied significantly ($p < 0.05$) across the size classes, with large seeds having the greatest thickness (7.53 ± 0.20 cm) and weight (4.18 ± 0.20 g), and small seeds the smallest dimensions (2.77 ± 0.19 cm length, 4.60 ± 0.20 cm thickness, 2.34 ± 0.19 g weight). Germination began earlier in small seeds (week 2) and progressed more rapidly compared to larger seeds, with small seeds achieving the highest final germination percentage (93.33%) and the shortest MGT (3.43 weeks). Large seeds exhibited the slowest germination, with the final germination occurring by week 8. Small seeds also exhibited higher GI (26.72) and CVG (0.0027), indicating faster and more uniform germination. Early seedling growth analysis revealed that small seeds produced the longest shoots (7.5 cm) and roots (4.5 cm). These results suggest that smaller seeds may be more suitable for rapid seedling establishment in nursery settings, whereas larger seeds may be better suited for environments requiring longer seedling development. The study emphasizes the importance of considering seed size in the conservation, domestication, and genetic improvement of *G. kola* to optimize propagation strategies and ensure sustainable management of this economically valuable species.

Keywords: *Garcinia kola*, seed size, germination performance, recalcitrant seeds, seedling establishment.

Introduction

Seed size is a fundamental life history trait that plays a crucial role in shaping plant ecology, population dynamics, and evolutionary strategies. It significantly influences key developmental processes such as seed germination, seedling emergence, establishment, growth rate, survival, competitive ability, plant stature, and reproductive success (Shaukat *et al*., 1999). The ecological and adaptive significance of seed size is well-documented, with numerous studies indicating that it affects a plant's ability to cope with environmental stressors, including water scarcity, nutrient availability, and competition (Venable & Brown, 1988; Stamp, 1990). Seed size is often positively correlated with the size of mature plants and their reproductive structures, influencing their overall fitness and regenerative capacity within plant populations (Staton, 1984a; Silvertown, 1989).

Along with dispersal and dormancy, seed size is one of three ecologically significant seed traits that collectively determine a plant species' ability to survive and establish in diverse environments. Larger seeds generally confer advantages such as higher energy reserves, which promote greater seedling vigor

and survival rates, particularly in resource-limited conditions. Conversely, smaller seeds are often produced in larger quantities and may exhibit rapid germination, allowing plants to colonize new habitats efficiently (Marshall, 1986; Zhang & Maun, 1990). Empirical studies have demonstrated the intraspecific effects of seed size on germination rate, seedling survival, and initial growth performance (Gross, 1984; Marshall, 1986; Zhang & Maun, 1990). For instance, seedlings derived from larger seeds often exhibit superior competitive ability, increasing their likelihood of reaching maturity, especially in environments where seedling mortality is influenced by factors such as water stress, limited growing seasons, and high interspecific competition. This advantage is primarily due to the ability of large seeds to develop more robust and deeply penetrating root systems, which enhance access to water and nutrients, thereby improving seedling establishment and resilience (McWilliams *et al*., 1968; Baker, 1972; Stanton, 1984b).

One tree species that exemplifies notable variation in seed size is *Garcinia kola*, a member of the Clusiaceae family, commonly known as bitter kola. *Garcinia kola* is a highly valued non-timber forest product with economic and ecological importance. It is widely used in traditional medicine, food, and pharmaceutical industries due to its bioactive compounds, which possess antimicrobial, anti-inflammatory, and antioxidant properties (Olatoye *et al*., 2024; Gogo *et al*., 2025). Despite its economic and ecological significance, *Garcinia kola* remains underutilized in domestication and genetic improvement programs, largely due to challenges associated with its seed dormancy, which complicates germination and propagation (Agyili *et al*., 2007). Enhancing seed germination is crucial for any successful plant development and conservation initiative, as it ensures better seedling establishment, improved productivity, and optimized yield. Our previous research efforts on the conservation and improvement of this important African-indigenous, threatened fruit species have focused on its genetic diversity (Olawuyi *et al*., 2019; Azeez *et al*., 2020).

While several studies have explored germination and early growth performance in *Garcinia kola*, a gap remains in understanding how seed size variation affects germination success. Given the role of seed size in influencing plant fitness and adaptability, investigating this relationship in *Garcinia kola* is essential for developing effective strategies for its conservation, large-scale propagation, and sustainable management. By examining how seed size influences seed germination, this study aims to provide valuable insights into best practices for seed selection in domestication and restoration efforts.

Materials and Methods

Seed Collection and Classification

Mature *Garcinia kola* fruits were randomly harvested from 10 different fruiting trees within the same population in Omifon Village, Odigbo Local Government Area, Ondo State, Nigeria. The seeds were extracted from the mucilaginous pulp, thoroughly washed with distilled water to remove contaminants, and air-dried at room temperature for 24 hours. A total of 250 seeds were obtained, and 30 seeds were randomly selected from each size category (small, medium, and large). These were used as replicates and arranged in a completely randomized design. Seed size was determined based on measurements of length, thickness, and weight, using a ruler, vernier caliper, and electronic weighing balance, respectively.

Pre-Treatment and Germination Conditions

To enhance seed germination, the seeds underwent a dormancy-breaking treatment following the protocol described by Yakubu *et al*. (2014). Treated seeds were then stored in sealed, labeled containers at room temperature until the germination study.

Germination Assessment and Growth Parameters

Seed germination was monitored daily over an eight-week period. The germination process was defined by the emergence of the radicle, extending at least 1 mm beyond the seed coat (Tripathi & Khan, 1990). The number of seeds that germinated was recorded at regular intervals, and the following germination parameters were calculated:

The germination percentage (GP) was calculated following the formula recommended by Cokkizgin & Cokkizgin (2010):

$$GP = Number\ of\ germinated\ seeds / Total\ number\ of\ seeds$$

Germination Index (GI) was recorded using the formula recommended by AOSA (1990). GI=$\Sigma GtDt$

Where Gt is the number of germinated seeds on day t, and Dt is the total number of days.

Coefficient of Germination Velocity (CVG) was calculated using the formula described by Maguire (1962):

$CVG = G1 + G2 + \cdots Gn$ ($1\times G1 + 2\times G2 + \cdots + \cdots + n\times Gn$)

Where *G* represents the number of germinated seeds recorded daily until the experiment concluded.

The Mean Germination Time (MGT) was computed using the formula provided by Ellis & Roberts (1981):

MGT= $\Sigma(nd)/\Sigma n$

Where *n* is the number of seeds germinated on a given day *d*, and Σn represents the total number of germinated seeds throughout the study period.

Seedling Growth Measurements

After the eight-week germination period, the root and shoot lengths of all germinated seedlings were measured. These measurements were taken using a ruler, and the mean root and shoot lengths were calculated for each seed size class.

Statistical Analysis

The data were analyzed using Analysis of Variance (ANOVA) to determine the significance of differences in germination and seedling growth parameters across the different seed size classes. Post-hoc comparisons were made using the Least Significant Difference (LSD) test, as described by Zar (2010). All statistical analyses were performed using SPSS for Windows, version 14, and relevant packages in RStudio.

Results and Discussion

The mean length, thickness, and weight of *Garcinia kola* seeds varied across the three size categories, ranging from 2.77 to 3.88 cm, 4.60 to 7.53 cm, and 2.34 to 4.18 cm, respectively (Table 1).

Seed Size Characteristics

Seed morphometric analysis revealed significant differences ($p < 0.05$) in seed length, thickness, and weight across the seed size classes (Table 1). Large seeds had the greatest thickness (7.53 ± 0.20 cm) and weight (4.18 ± 0.20 g), followed by medium seeds (5.21 ± 0.19 cm thickness; 3.25 ± 0.21 g weight), while small seeds had the lowest values for both parameters (4.60 ± 0.20 cm thickness; 2.34 ± 0.19 g weight). Seed length differed significantly between small seeds (2.77 ± 0.19 cm) and both medium (3.87 ± 0.21 cm) and large seeds (3.88 ± 0.19 cm), which were statistically similar ($p > 0.05$). These results confirm clear size-related distinctions among the seed classes, particularly in seed thickness and weight.

Table 1a: Analysis of Variance (ANOVA) for Seed Morphological Traits of *Garcinia kola*

Seed trait	F-statistic	P-value
Seed Length (cm)	889.27	2.6E-113
Seed Thickness (cm)	5154.63	1.6E-201
Seed Weight (g)	1697.62	1.1E-144

Table 1b: Tukey's HSD Post Hoc Test for Pairwise Comparison of Seed Morphological Traits in *Garcinia kola*

(a) Seed length

	group1	group2	meandiff	p-adj	lower	upper	reject
0	Large	Medium	-0.01	0.97	-0.08	0.06	FALSE
1	Large	Small	-1.11	0	-1.18	-1.04	TRUE

2	Medium	Small	-1.10	0	-1.17	-1.03	TRUE

(b) Seed thickness

	group1	group2	meandiff	p-adj	lower	upper	Reject
0	Large	Medium	-2.31	0	-2.38	-2.24	TRUE
1	Large	Small	-2.92	0	-3.00	-2.85	TRUE
2	Medium	Small	-0.61	0	-0.68	-0.54	TRUE

(c) Seed weight

	group1	group2	meandiff	p-adj	lower	upper	reject
0	Large	Medium	-0.93	0	-1.01	-0.86	TRUE
1	Large	Small	-1.84	0	-1.91	-1.76	TRUE
2	Medium	Small	-0.90	0	-0.98	-0.83	TRUE

Table 1d**:** Variation in morphometric traits

Seed Size	Seed length (cm)	Seed thickness (cm)	Seed weight (g)
Small seeds	2.77 ± 0.19^{b}	4.60 ± 0.20^{c}	2.34 ± 0.19^{c}
Medium seeds	3.87 ± 0.21^{a}	5.21 ± 0.19^{b}	3.25 ± 0.21^{b}
Large seeds	3.88 ± 0.19^{a}	7.53 ± 0.20^{a}	4.18 ± 0.20^{a}

Means with the same letter in the same column are not significantly different at $p<0.05$ using Duncan's Multiple Range Test (DMRT)

SEEDS Germination Dynamics Across Seed Sizes

The germination response of *Garcinia kola* seeds varied significantly across the three seed size categories (Table 2). Small seeds exhibited the highest final germination percentage (% FG) of 93.33%, followed by large seeds (90%) and medium seeds (83.33%). Germination in all seed sizes commenced in the second or third week, with the highest germination activity occurring between the third and fifth weeks. Small seeds reached their peak germination in Week 4 (15 seeds), while medium and large seeds had their highest germination counts in Weeks 4 and 5, respectively.

Table 2: Effects of Seed Size on Germination Performance of *Garcinia kola*

Seed size	Small	Medium	Large
Week 1	0	0	0
Week 2	2	0	0
Week 3	8	4	0
Week 4	15	12	6
Week 5	3	5	15
Week 6	0	0	2
Week 7	0	4	2
Week 8	0	0	2
Total	28	25	27
% FG	93.33	83.33*	90
MGT	3.43	3.77	4.70*
FWG	2	3	4
LWG	5	7	8
CVG	0.0027	0.0022	0.0019*
GI	26.72	19.67	17.89

Note: FG: Final Germination, MGT: Mean Germination Time (weeks), FWG: First Week of Germination, LWG: Last Week of Germination, CVG: Coefficient of Velocity of Germination, GI: Germination Index. Mean values indicated with * are statistically significant at $p < 0.05$.

Germination Timing

Mean Germination Time (MGT) increased with seed size, with small seeds germinating the fastest (MGT = 3.43 weeks), followed by medium seeds (3.77 weeks), and large seeds exhibiting the slowest germination (MGT = 4.7 weeks). The Germination Index (GI) also showed a decreasing trend with increasing seed size, with small seeds having the highest GI (26.72), followed by medium (19.67) and large seeds (17.89) (Table 2). It indicates that smaller seeds germinated more rapidly and uniformly compared to larger seeds.

Temporal Distribution and Germination Spread

The First Week of Germination (FWG) and Last Week of Germination (LWG) values further supported the observed trend, with small seeds having a more concentrated germination period (FWG = 2 weeks, LWG = 5 weeks). In comparison, medium and large seeds exhibited extended germination periods (FWG = 3 and 4 weeks, LWG = 7 and 8 weeks, respectively). The Coefficient of Velocity of Germination (CVG) was highest for small seeds (0.0027), indicating a faster germination rate compared to medium (0.0022) and large seeds (0.0019) (Table 2).

Seed Size Effects on Early Seedling Growth Parameters

Germination commenced earliest in the small-sized seeds, with the first emergence observed within the first week (Fig. 1 and 2), and enhanced early growth vigor was was associated with smaller seed sizes (Fig. 1).

Fig. 1. Germinated seedlings from different seed size classes. Small seeds exhibited more advanced shoot and root development compared to medium and large seeds, consistent with measured shoot and root lengths.

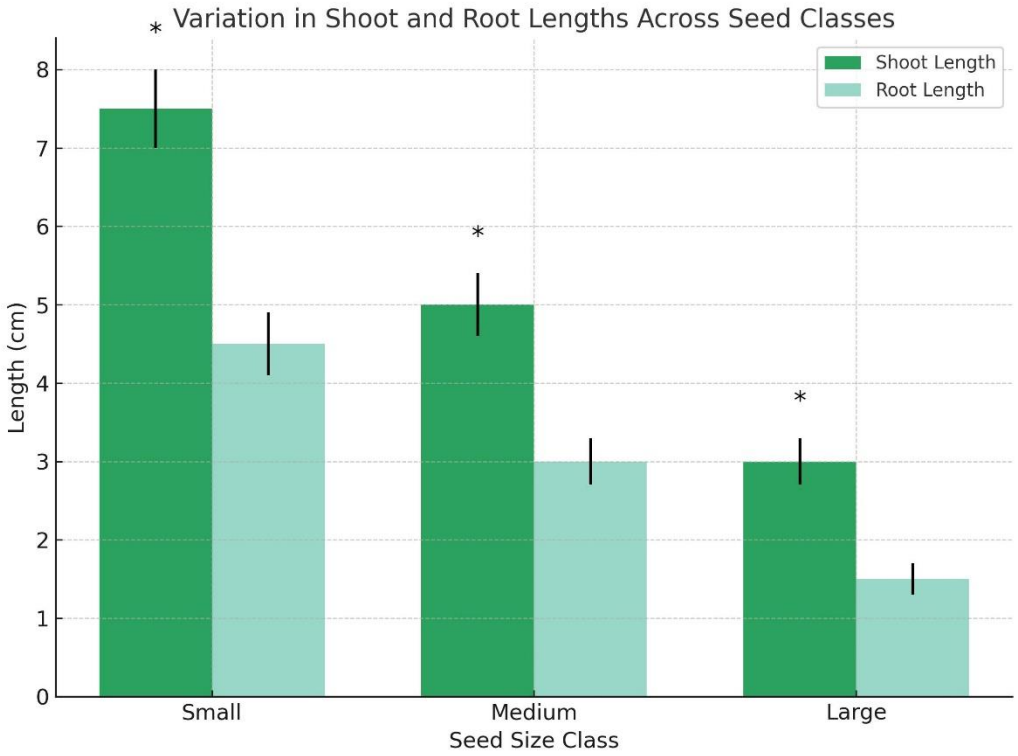

Fig. 2. Variation in shoot and root length across seed classes. Mean values indicated with * are statistically significant at $p < 0.05$.

Variation in shoot and root lengths was observed across the seed size classes (Fig. 2). Small seeds produced the longest shoots (7.5 cm) and roots (4.5 cm), followed by medium seeds, which had shoot and root lengths of 5 cm and 3 cm, respectively. The shortest shoot (3 cm) and root (1.5 cm) lengths were recorded in large seeds. Statistical analysis revealed that shoot length differed significantly ($p < 0.05$) among the seed size classes, with a progressive decrease in length as seed size increased. Although root length showed a similar declining trend with increasing seed size, the differences were not

statistically significant ($p > 0.05$). These results indicate that smaller seeds promote more vigorous shoot development during early seedling growth compared to larger seeds.

Germination increased significantly, peaked in the fourth week, and concluded by the fifth week. In the medium-sized seeds, germination was delayed until the third week, peaked in the fourth week, and followed a similar declining trend as the small seeds by the fifth week. However, a secondary germination event was observed in the seventh week. Large seeds exhibited the most delayed germination, beginning in the fourth week, peaking in the fifth week, and subsequently declining, with the final germination occurring in the eighth week.

Final germination percentages differed significantly among seed size classes ($p < 0.05$), with small seeds achieving the highest germination rate (93.33%) and medium seeds the lowest (83.33%). Mean Germination Time (MGT) also varied significantly with seed size ($p < 0.05$), increasing progressively from small to large seeds (Small < Medium < Large). Large seeds exhibited the longest MGT, indicating slower germination, while small seeds germinated the fastest.

Significant differences were also noted in the timing of germination events. The earliest and latest germination occurred in small seeds (weeks 2 and 5), while large seeds displayed a broader germination window, beginning in week 4 and extending to week 8.

Furthermore, the Coefficient of Velocity of Germination (CVG) declined significantly with increasing seed size, reflecting slower and less uniform germination in larger seeds (Table 2). A similar trend was observed in the Germination Index (GI), which also decreased significantly as seed size increased. These results indicate that smaller seeds not only germinate more rapidly but also exhibit greater uniformity in germination compared to larger seeds.

Seed size had a significant effect on shoot and root length, as well as other germination parameters. Small seeds produced the longest shoots and roots, while large seeds exhibited the shortest measurements. This finding contrasts with the report by Shipley and Parent (1991), which found no relationship between seed size and germination attributes, including germination time, in certain wetland annual and facultative species. The observed negative correlation between germination velocity, MGT, CVG, GI, and seed size further reinforces the advantage of smaller seeds in terms of faster and more efficient germination. The variation in germination patterns among seed size classes may be attributed to differences in metabolic activity, energy allocation, and seed coat permeability, as similarly reported by Nzegbule and Mbakwe (2001) and Agyili *et al*. (2007). While large seeds typically store more reserves, their delayed germination may result from thicker seed coats, which act as physical barriers to water and gas exchange. Conversely, smaller seeds, despite having fewer reserves, exhibit faster germination, possibly due to higher metabolic efficiency and reduced dormancy constraints.

These findings have important ecological and silvicultural implications for the propagation and conservation of *Garcinia kola*. The superior germination performance of smaller seeds suggests they may be more suitable for rapid seedling establishment in nursery settings. In comparison, larger seeds might be better suited for environments where prolonged seedling development is advantageous. Further research is needed to assess the long-term growth performance of seedlings from different seed size classes and their potential impact on the success of plantations. Additionally, other potential factors contributing to the superior performance of small seeds, particularly their phytochemical composition, should be investigated in future studies.

Conclusion and Recommendations

This study has demonstrated that seed size significantly influences the germination performance of *Garcinia kola*, with important implications for its successful plantation establishment. Given the ongoing challenges related to the conservation and domestication of the species, understanding the role of seed size in early seedling development provides a valuable strategy for improving propagation success.

Based on these findings, it is recommended that seed size should be carefully considered when selecting *Garcinia kola* seeds for domestication, genetic improvement, and conservation efforts. Prioritizing seeds with optimal germination traits can enhance seedling establishment, ultimately contributing to the sustainable management of this economically and medicinally important species.

Furthermore, additional research is needed to investigate the long-term effects of seed size on growth

descriptors such as biomass accumulation, leaf development, and overall plant vigor. Such studies will provide deeper insights into how seed size influences not just early germination but also the long-term survival and productivity of *Garcinia kola* in different ecological settings.

Implications for Seedling Establishment

The findings suggest that seed size plays a crucial role in germination performance, with small seeds germinating more quickly and uniformly, potentially providing an advantage in the rapid establishment of seedlings. However, large seeds, despite their slower germination, may contribute to improved seedling vigor and long-term survival. These variations underscore the ecological importance of seed size in Garcinia kola, offering insights for conservation and large-scale propagation strategies.

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IRON PHOSPHATE DISTRIBUTION PATTERN ALONG SOIL DEPTH GRADIENT IN DIFFERENT TROPICAL LAND USE TYPES

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ABSTRACT

The study was designed to assess iron phosphate distribution patterns along soil depth gradients in different rainforest land use types in the Federal University of Agriculture, Abeokuta, Ogun State, Nigeria. The study was a 5×3 factorial experiment in a Randomized Complete Block Design (RCBD). The five different land use practices, viz: *Gmelina arborea*, *Tectona grandis*, *Leucaena leucocephala,* plantations, secondary forest and abandoned farmland constitute the treatments; while the three soil depths per site (0-30 cm, 30-60 cm and 60-90 cm) were the treatment levels replicated three times. Soil concentrations of organic matter, iron phosphate, and pH were collected as data. Analysis of variance (ANOVA) was used to analyse the significance of variation in pH, organic matter, and iron-phosphate (Fe-P) between land use types and along a soil depth gradient. Mean separation was conducted using the Tukey mean grouping method, and descriptive statistics were used to estimate the the mean and standard deviation. We found that iron-phosphate concentration was directly related to organic matter. *Tectona grandis, Gmelina arborea,* and *Leucaena leucocephala,* which are mono plantations, recorded the highest concentrations of iron-phosphate than the secondary forest and abandoned farmland. The contraction of the pattern of iron-phosphate occurrence in the study area, in conjunction with literature evidence, suggests the need for information on the history of the different land-use types.

Keywords: organic matter, pH, phosphorus, plantation, natural forest.

INTRODUCTION

Phosphorus (P) is one of the major and essential nutrients that determine the function and primary productivity of terrestrial ecosystems (Elser *et al.,* 2007). It has a chemical symbol of P with atomic number 15. Some soils exhibit a very low capacity to supply sufficient phosphorus (P) for crop production, despite its importance. It stimulates the growth of young plants, providing them with a strong and vigorous start. Phosphorus stress early in the growing season reduces crop productivity more than P restrictions later in the crop cycle (Grant & Flaten, 2019). An inadequate concentration of phosphorus slows down early plant growth, limits root system development, and causes plants to become dwarfed, exhibiting a purplish discoloration of the stems, petioles, and lower sides of the leaves (Karthika *et al.,* 2018). Despite the large volume of P stock present in soils (Hirano et al., 2022), soil P release is often insufficient to meet the P needs of plants in terrestrial ecosystems (Aerts and Chapin, 1999). It is largely due to multiple forms of P existing in the soils, which differ in their availability for plant uptake across time scales (Hedley *et al.,* 1982; Chen *et al.,* 2003).

Phosphorus exists in two main forms in the soil, i.e., organic and inorganic forms (Hedley *et al.,* 1982). Organic forms of phosphorus include: available phosphorus and total phosphorus, to mention a few, while inorganic phosphorus (P) exists in compounds with Aluminum (Al), Iron (Fe), and Calcium (Ca) in the soil, and they exhibit variation in their solubility and availability to plants. Meanwhile, the chemical

fractionation of soil inorganic phosphorus(P) provides a technique for determining the predominant individual forms of inorganic P in soils; the most commonly soluble P compound are; aluminium P (Al-P), iron P (Fe-P), occluded P and calcium P (Ca-P) (Chen *et al.*2003). However, Igwe (2001) asserted that phosphorus fixation is a common occurrence in tropical soils due to the high volume of Iron (Fe) and Aluminum (Al) hydrous oxides. Soil pH determines the type of phosphorus fixation that occurs; acidic soils tend to fix either Iron (Fe) or Aluminum (Al) phosphorus compounds, while alkaline soils fix Calcium (Ca) phosphorus compounds (Havlin *et al.,* 2001). Soil characterization provides the information necessary for our understanding of the physical, chemical, biological, and mineralogical properties of the soils we depend on for crop growth, sustaining forests, and grasslands (Ogunkunle & Eghaghara, 1992). Differences in land use practices influence the diverse forms of phosphorus, resulting from environmental factors and activities that have occurred on the land. Variations in phosphorus availability and forms can be determined on various land use practices (farmland, plantation, degraded sites, and secondary forest). However, many researchers including Ogunkunle & Eghaghara, (1992) as well as Yang & Post, (2011) opined that soil P fractions determined by sequential fractionation technique can give useful information on the availability and dynamics of soil P and its responses to various environmental or anthropogenic factors in terrestrial ecosystems. Thus they have been widely used to date. The accessibility of P to plants depends on the soil characteristics, which determine the degree of sorption and desorption of P, including clay content and mineralogy, organic matter, soil pH, and exchangeable Al, Fe, and Ca concentrations in the soil solution. The study was designed to assess iron phosphate distribution patterns along a soil depth gradient in different rainforest land use types at the Federal University of Agriculture, Abeokuta, Ogun State, Nigeria.

MATERIALS AND METHODS

Study area

Ogun State lies appropriately between Longitude 2’30’E and 4’30’E and between 6’30’and 80’N (Sam-wobo and Mafiana 2005). It is located in the rainforest ecological zone of Nigeria. Five different land-use practices were selected at the Federal University of Agriculture, Abeokuta, Nigeria, for the study. The institute is situated appropriately between longitude 7°23" – 7°58" N and between latitude 3°25" – 3°43" E, within Abeokuta in Ogun State.

Experimental Design

The study was a 5×3 factorial experiment laid out in a Randomized Complete Block Design (RCBD). The five different land use practices viz: *Gmelina arborea*, *Tectona grandis*, *Leucaena leucocephala* plantations, Secondary Forest, and Abandoned farmland constitute the treatments; while the three soil depths per site (0-30 cm, 30-60 cm, and 60-90 cm) were the treatment levels replicated three times. Soil analysis was conducted using standard laboratory methods.

Soil Preparation and Analysis

The soil samples collected from the study locations were immediately stored in polyethylene bags before being transported to the laboratory. All soil samples were air-dried for 3 days at room temperature to remove moisture and then sieved through a 2 mm diameter sieve. The pH of the soil samples was determined in water using a Beckman’s pH meter using a soil ratio of 1:2.5 (Mukhopadhyay *et al.* 2019). Soil organic matter was determined by the procedure of Walkley and Black (1934) using the dichromate wet oxidation method (Pellerin *et al.* 2006). Soil H^+ was determined following the laboratory standard procedure (Silva *et al.,* 2000). The characterization of the different forms of inorganic phosphorus in soils was carried out using sequential extraction with acid and alkaline reagents, as reported by Murphy and Riley (1962) and later modified by Aerts and Chapin (1999). The procedures used were modifications and improvements of the sequence-based extraction method using acid and alkaline reagents, originally suggested by Chen et al. (2003). The phosphorus concentration in the various extracts was determined using the phosphomolybdate method (Elser *et al.,* 2007).

Data Analysis

Analysis of variance (ANOVA) was used to analyse the significance of variation in pH, organic matter, and iron-phosphate (Fe-P) between land use types and along the soil depth gradient. Mean separation was conducted using the Tukey mean grouping method, and descriptive statistics were used to estimate the mean and standard deviation.

RESULTS

Iron phosphate (**Fe-P) distribution pattern between rainforest land use types at 0-30cm soil depth.**

Iron phosphate (Fe-P) presence at 0-30 cm soil depth was significantly highest in the *Tectona grandis* plantation (3.14±0.25 mg/kg), followed by *Leuceana leucocephala* plantation (2.62±0.58 mg/kg), *Gmelina arborea* plantation (1.69±0.30 mg/kg), secondary forests (0.94±0.24 mg/kg), and the lowest was the abandoned farmland (0.62±0.05 cm). There were significant differences in iron phosphate (Fe-P) concentration between the land use types at the 0-30 cm soil depth. Mean separation showed that at a soil depth of 0-30 cm, Fe-P concentration was not significantly different between the Tectona grandis, Gmelina arborea, and Leucaena leucocephala plantations; however, these were significantly higher than in the secondary forest and the abandoned farmland (Table 1). Mean pH was highest in the *Tectona grandis* (6.80±0.1), followed by *Leuceana leucocephala* (6.96±0.02), *Gmelina arborea* (6.13±0.03), secondary forest (6.47±0.49), and abandoned farmland (5.9±0.01). There were significant differences in pH between the land use types. Mean separation showed that there were no significant differences in pH between Tectona grandis, Leucaena leucocephala, Gmelina arborea, and secondary forest, but these were significantly higher than those in abandoned farmland. Soil organic matter (OM) was significantly highest in the *Tectona grandis* (16.99±0.04) plantation, followed by *Leuceana leucocephala* (16.89±0.003), *Gmelina arborea* (16.47±0.26), secondary forest (14.74±0.09), while the significantly lowest was recorded (11.6±0.05) (Table 1).

The results further showed that the mono-plantations (*Tectona grandis, Leuceana leucocephala,* and *Gmelina arborea*) which accumulated higher iron-phosphate also recorded higher organic matter accumulation as well as higher pH (close to neutral) (Figure 1) thus showing a positive correlation between the three factors, viz, Fe-P presence increased with increased organic matter and pH.

Table 1. Mean pH and concentration of Fe-P at 0-30cm soil depth between different rainforest land use types.

Land use types	pH	Fe-P (mg/kg)	Organic matter (%)
Teak	6.80±0.1^{a}	3.14±0.25^{a}	16.99±0.04^{a}
Leu	6.96±0.02^{a}	2.62±0.58^{ab}	16.89±0.003^{b}
Gmelina	6.13±0.03^{a}	1.68±0.30^{b}	16.47±0.26^{b}
SECONF	6.47±0.49^{a}	0.94±0.24^{c}	14.74±0.09^{c}
ABFML	5.9±0.01^{b}	0.62±0.05^{c}	11.6±0.05^{d}

***Means with different letters are significantly different. Teak = *Tectona grandis;* Leu = *Leuceana leucocephala;* Gmelina = *Gmelina arborea;* SECONF = secondary forest; ABFML = abandoned farmland.**

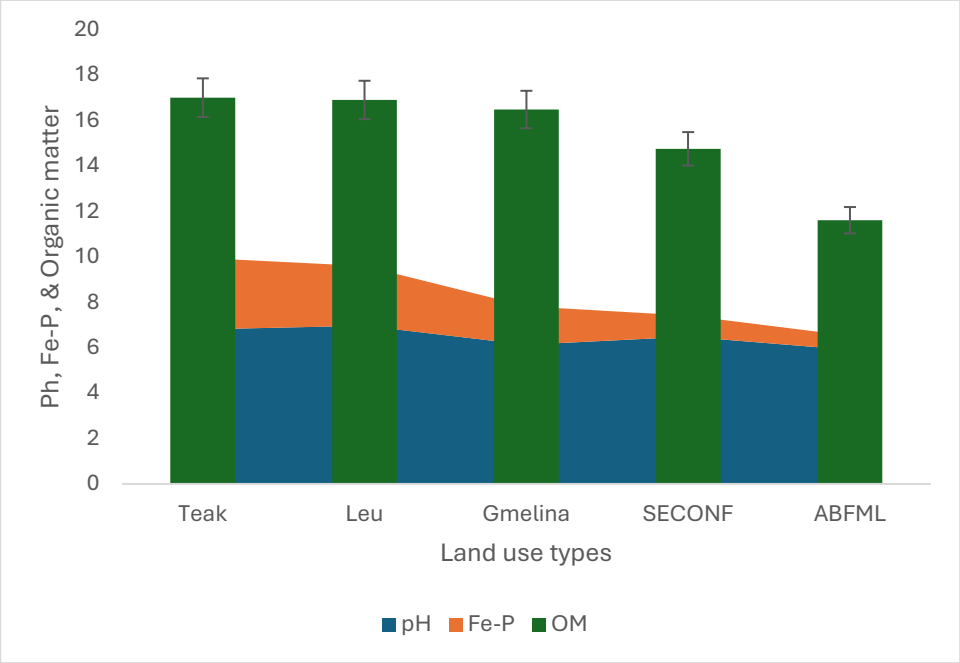

Figure 1. Pattern of Fe-P, Organic matter (OM), and pH variation among rainforest land use types at 0-30cm soil depth. ** Teak = *Tectona grandis;* Leu = *Leuceana leucocephala;* Gmelina = *Gmelina arborea;* SECONF = secondary forest; ABFML = abandoned farmland.

Fe-P distribution pattern between rainforest land use types at 30-60cm soil depth

The highest mean concentration of iron phosphate (Fe-P) at 30-60cm soil depth was recorded in the *Tectona grandis* plantation (2.37±0.47cm), followed by *Leuceana leucocephala* (2.01±0.01cm), abandoned farmland (1.66±0.31cm), secondary forest (0.49±0.20cm), and the lowest was *Gmelina arborea* (0.11±0.02). There were significant differences in iron phosphate (Fe-P) concentration between the land use types at a soil depth of 30-60 cm. Mean separation showed that at a soil depth of 30-60 cm, Fe-P concentration was not significantly different between the Tectona grandis plantation, the Leucaena leucocephala plantation, and the abandoned farmland; however, it was significantly higher than in the secondary forest and the *Gmelina arborea* plantation. The concentration in the secondary forest and the *Gmelina arborea* were significantly lower, while the *Gmelina arborea* plantation was the lowest. (Table 2). Abandoned farmland recorded significantly the highest (5.95±0.1) pH at this soil depth, followed by *Leuceana leucocephala* (5.85±0.09), *Gmelina arborea* (5.58±0.02), secondary forest (5.23±0.03), while the significantly lowest was *Tectona grandis* (5.22±0.01). Organic matter accumulation was significantly highest in *Tectona grandis* (9.22±0.16), followed by *Leuceana leucocephala* (15.39±0.06), abandoned farmland (8.76±0.13), and secondary forest (8.83±0.01), while the lowest was *Gmelina arborea* (9.2±0.06) (Table 2).

The pattern of organic carbon, Fe-P, and pH concentration at 30-60cm soil depth was equally similar to 0-30cm; high concentration Fe-P correlated with high organic matter and pH; in this regard, the mono-plantations (except *Gmelina arborea*) yet again recorded the highest concentrations of Fe-P, organic matter, and pH than the abandoned farmland and secondary forest (Figure 2).

Table 2. Mean Ph and concentration of Fe-P at 30-60cm soil depth between different rainforest land use types.

Land use types	pH	Fe-P (mg/kg)	Organic matter (%)
Teak	5.22±0.01^{c}	2.37±0.47^{a}	9.22±0.16^{b}

Leu	5.85±0.09[a]	2.01±0.01[a]	15.39±0.06[a]
ABFML	5.95±0.1[a]	1.66±0.31[a]	8.76±0.13[c]
SECONF	5.23±0.03[c]	0.49±0.21[b]	8.83±0.01[c]
Gmelina	5.58±0.02[b]	0.11±0.02[b]	9.2±0.06[b]

*Means with different letters are significantly different. Teak=*Tectona grandis*; Leu=*Leuceana leucocephala*; Gmelina=*Gmelina arborea*; SECONF=secondary forest; ABFML=abandoned farmland.

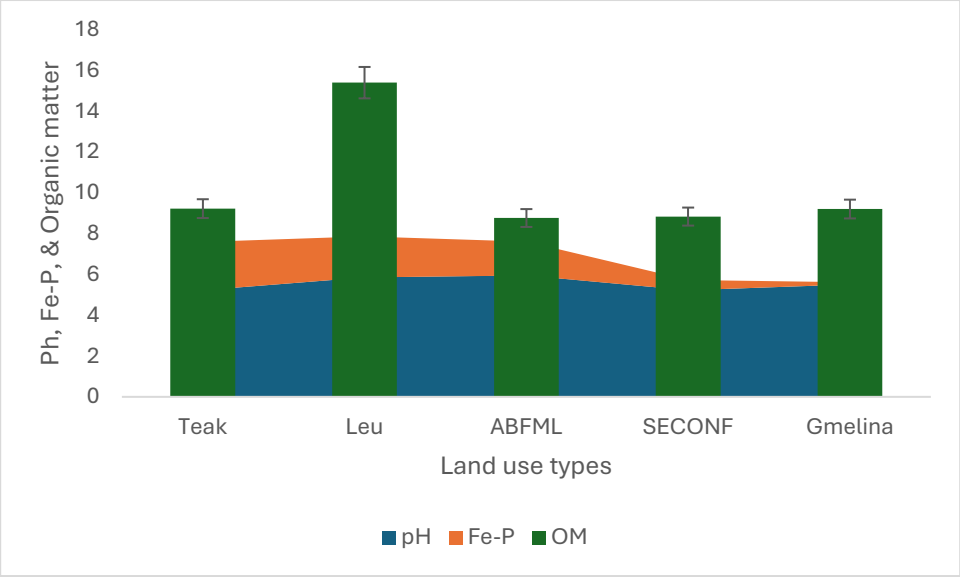

Figure 2. Pattern of Fe-P, Organic matter (OM), and pH variation among rainforest land use types at 30-60cm soil depth. ** Teak = *Tectona grandis;* Leu = *Leuceana leucocephala;* Gmelina = *Gmelina arborea;* SECONF = secondary forest; ABFML = abandoned farmland.

Fe-P distribution pattern between rainforest land use types at 60-90cm soil depth.

The highest concentration of Fe-P was recorded in the abandoned farmland (2.32±0.66 mg/kg), followed by the secondary forest (2.16±0.19 mg/kg), *Leuceana leucocephala* (2.09±0.54 mg/kg), *Tectona grandis* (0.76±0.03 mg/kg), and the lowest was *Gmelina arborea* (0.14±0.02 mg/kg). There were significant differences in iron phosphate (Fe-P) concentration between the land use types at a soil depth of 60-90 cm. Mean separation showed that Fe-P concentration at 60-90 cm soil depth was not significantly different between abandoned farmland, secondary forest, and *Leuceana leucocephala* plantation; but was significantly higher than *Tectona grandis* and *Gmelina arborea*; the concentration in the *Tectona grandis* plantation was significantly higher than *Gmelina arborea,* which was significantly the lowest (Table 3). Thus, indicating that at 60-90 cm soil depth, *Leuceana leucocephala,* alongside abandoned farmland and secondary forest accumulated significantly far more Fe-P than *Tectona grandis* and *Gmelina arborea*

Abandoned farmland recorded significantly the highest pH (5.65±0.05), followed by *Leuceana leucocephala* (5.55±0.24), *Gmelina arborea* (5.33±0.03), *Tectona grandis* (5.19±0.38), and the significantly lowest was recorded in the secondary forest (5.11±0.04); organic matter accumulation was significantly highest in the *Leuceana leucocephala* (9.65±0.01) plantation, followed by *Gmelina arborea,* (9.42±0.06) *Tectona grandis,* (9.31±0.17) abandoned farmland, 9.18±0.01b. In contrast, the significantly lowest was recorded in the secondary forest (8.08±0.01) (Table 3).

Abandoned farmland recorded significantly high pH and hence high Fe-P, albeit at low organic matter; *Leuceana leucocephala,* however, had high pH, Fe-P, and organic carbon; whereas, the low pH of the secondary forest alongside *Tectona grandis* and *Gmelina arborea* translated to low Fe-P presence

despite high organic matter. Effectively, therefore, pH was the key determinant of Fe-P concentration rather than organic matter (Figure 3).

Table 3. Mean pH and Fe-P concentration at 60-90cm soil depth in different land use types

Factor	pH	Fe-P (mg/kg)	Organic matter (%)
ABFML	5.65±0.05^{a}	2.32±0.66^{a}	9.18±0.01^{b}
SECONF	5.11±0.04^{ab}	2.16±0.19^{a}	8.08±0.01^{c}
Leu	5.55±0.24^{a}	2.09±0.54^{a}	9.65±0.01^{a}
Teak	5.19±0.38^{ab}	0.76±0.03^{b}	9.31±0.17^{b}
Gmelina	5.33±0.03^{ab}	0.14±0.02^{c}	9.42±0.06^{b}

Means with different superscripts are significantly different. Teak = *Tectona grandis*; Leu = *Leuceana leucocephala*; Gmelina = *Gmelina arborea*; SECONF = secondary forest; ABFML = abandoned farmland.

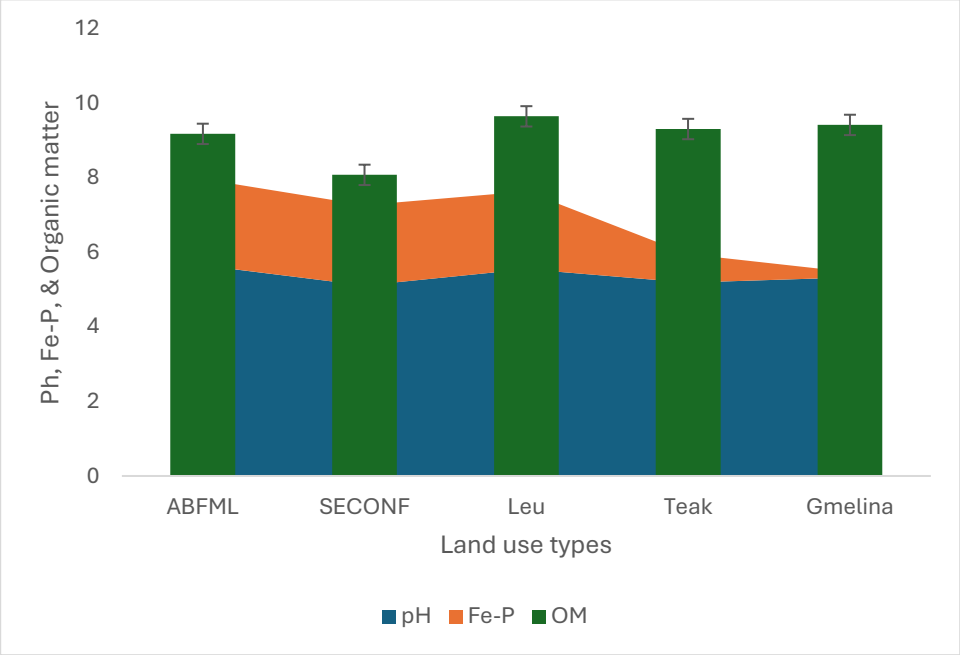

Figure 3. Pattern of Fe-P, Organic matter (OM), and pH variation among rainforest land use types at 60-90cm soil depth. **Teak = *Tectona grandis;* Leu = *Leuceana leucocephala;* Gmelina = *Gmelina arborea;* SECONF = secondary forest; ABFML = abandoned farmland.

DISCUSSION

The invaluable position of phosphorus in plant nutrition is underscored by the fact that up to 0.2% of the dry weight of plant material is made up of phosphorus (Hou *et al.,* 2014). This fact makes Phosphorus the second most vital soil nutrient after nitrogen and makes it critical to plant growth and development. Iron-phosphate is one of the inorganic forms of phosphorus normally found in acid soils (Frasar *et al.*, 2015). Phosphorus in the form of iron phosphates is normally not readily available to plants due to the very slow rate of release or immobilization. The pattern of iron-phosphate occurrence in the land

use types investigated in this study was consistent across all three levels of soil depth (0-30 cm, 30-60 cm, and 60-90 cm); a high positive correlation was observed between iron phosphate (Fe-P), pH, and soil organic carbon. Soil acidity and organic matter levels significantly influenced the concentration of iron phosphate in the land use types. It is contrary to the well-known relationship between soil acidity, organic matter, and iron phosphate, which is an inverse relationship where increased soil acidity and organic matter inhibit the precipitation of iron phosphates (Negassa and Leinweber, 2009). Organic matter is known to augment soil phosphorus through the process of mineralization, while soil pH between 6 and 7 is unsuitable for the formation of iron-phosphate (Achat *et al.,* 2010). Albeit, there are occasions when the iron-phosphate concentrate will increase despite high acidity and organic matter. It can occur in iron-rich soils, in which case there will be a need to investigate the iron composition of the study area's soils (Norra *et al.* 2008). Erosion could also be responsible; for example, we found that even in the topsoil (0-30cm soil depth (Table 1 and Figure 1) where we recorded the highest organic matter and soil pH, iron phosphate presence still increased. Another reason for the direct relationship between pH, organic matter, and iron phosphate found in this study is that the age of the land cover in these land use types may contribute to high iron phosphate presence. The long period before the introduction of vegetation cover over a land in a rainforest zone could result in the accumulation of iron phosphate, which would require time to be broken down or desorbed (Norra *et al.* 2008; Dieter *et al*. 2010). In this regard, this could be the reason that the highest concentration of iron phosphate was recorded in the mono plantations at the 0-30 cm and 30-60 cm soil depths, while at the 60-90 cm soil depth, the abandoned farmland and the secondary forest recorded high iron phosphate concentrations. While the plantations are still recovering from a prolonged period without cover, the abandoned forest and secondary forest have experienced leaching of iron-phosphate into the lower soil layers.

CONCLUSION

The mono plantations (*Gmelina arborea, Tectona grandis,* and *Leuceana leucocephala*) recorded the highest concentration of iron phosphate (Fe-P) at 0-30cm and 30-60cm soil depths, while the abandoned farmland and secondary forest recorded high Fe-P at 60-90cm soil depth. The high concentration of Fe-P in the presence of high pH and organic matter highlights the need for information on the plantation's history. Fe-P normally ought to decrease with increased pH and organic matter. Since our findings contradict empirical evidence from the literature, there is a need for further investigation of the study site to identify the possible cause.

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HARNESSING INSECT FRASS AS AN ORGANIC AMENDMENT FOR FOREST NURSERY DEVELOPMENT IN NIGERIA

Abstract

Forest nurseries in Nigeria play a central role in reforestation and ecological restoration initiatives, but they continue to face challenges such as low soil fertility, reduced seedling vigor, and poor survival rates after transplantation. Insect frass—a nutrient-rich by-product of insect farming comprising excreta, exuviae, and residual feed—has emerged globally as a promising organic amendment due to its balanced nutrient composition, presence of growth-promoting bioactive compounds, and beneficial microorganisms. Despite its demonstrated benefits in agriculture and horticulture, the application of this technology in forest nursery systems, particularly within tropical contexts such as Nigeria, remains underexplored. This study employed a systematic review of peer-reviewed articles, institutional reports, and grey literature published between 2000 and 2024, sourced from databases including Scopus, Google Scholar, Web of Science, and ScienceDirect. The review synthesizes current knowledge on the physicochemical properties of insect frass, its effects on soil quality and plant growth, and its potential integration into forest nursery practices. Key findings highlight the suitability of insect frass for enhancing soil structure, improving nutrient availability, and promoting seedling performance. Critical research gaps are also identified, including the lack of species-specific trials for native forest trees. The paper concludes by outlining future research directions and promoting insect frass as a sustainable, locally adaptable input for forest nursery development in Nigeria.

Keywords: Insect frass, organic amendment, forest nursery, seedling development, sustainable forestry

Introduction

Forest nurseries are vital components of sustainable forestry, providing seedlings needed for afforestation, reforestation, ecological restoration, and agroforestry programs in Nigeria (Akpan-Ebe, 2017; Oyetunji et al., 2020). However, nursery operations in Nigeria face persistent challenges, including low soil fertility, poor soil structure, and declining seedling vigor, which often result in low survival rates after transplantation (Olubode *et al.,* 2018; Mekouar, 2018). These challenges are exacerbated by limited access to high-quality organic soil amendments and the over-dependence on inorganic fertilizers, which may not sustainably address soil degradation in the long term (Shakywal *et al*., 2023).

In recent years, insect frass, a by-product of insect farming consisting of insect excreta, exuviae, and residual feed, has gained global attention as an alternative and sustainable organic fertilizer (Phurailatpam and Khwairakpam 2023; Beesigamukama *et al*., 2023). Insect frass, particularly from black soldier fly (*Hermetia illucens*) larvae, mealworms (*Tenebrio molitor*), and cricket species (*Gryllidae spp*.), has been reported to be rich in essential nutrients such as nitrogen, phosphorus, potassium, and trace elements (Beesigamukama *et al*., 2022). Additionally, it contains bioactive compounds, such as chitin, which enhances soil microbial activity and stimulates plant defense mechanisms (Mabelebele *et al*., 2023). Studies have demonstrated the ability of insect frass to enhance soil structure, increase nutrient availability, and improve the growth and yield of horticultural and crops (Beesigamukama *et al*., 2022). Despite these promising results, its application in forest nursery operations, especially within tropical and subtropical regions such as Nigeria, remains largely unexplored.

Nigeria has witnessed the rise of insect farming initiatives for sustainable protein production and organic waste recycling (Abajue and Gbarakor, 2023). This trend generates substantial quantities of insect frass, offering a potentially cost-effective and eco-friendly organic amendment for forestry purposes. However, critical questions regarding its suitability for forest nursery soil amendment, its influence on native forest species, and its long-term impacts on soil-plant interactions remain unanswered. This review, therefore, synthesizes existing knowledge on the composition and application of insect frass as an organic amendment, with a focus on its potential to address soil fertility constraints and enhance seedling development in Nigerian forest nurseries. The review further highlights knowledge gaps, challenges, and

prospects for integrating this approach into sustainable forest nursery management.

Methodology

Sources and Selection of Literature

This review employed a systematic approach to gather and synthesize literature related to the use of insect frass as an organic amendment for forest nursery development. Relevant peer-reviewed journal articles, technical reports, institutional documents, conference proceedings, and grey literature were consulted. The literature search was conducted using multiple online academic databases, including Google Scholar, Scopus, Web of Science, ScienceDirect, AgricOLA, and ResearchGate. Search terms such as *insect frass*, *organic fertilizer*, *forest nursery*, *seedling development*, *soil fertility*, *black soldier fly frass*, *organic amendments*, and *Nigerian forestry* were used to retrieve relevant publications. In addition, international and national forestry manuals and guidelines were reviewed to contextualize the application of insect frass within Nigerian forestry practices.

Defined criteria guided the selection of literature to ensure relevance and quality. Studies were included if they provided information on the nutrient composition of insect frass, its effects on soil fertility, plant growth, or soil biological activity. Emphasis was placed on studies published between 2000 and 2024 to capture contemporary developments, although foundational studies outside this range were also considered. Articles focusing on agricultural and horticultural crops were included when their findings had potential relevance to forest nursery operations. Studies conducted in tropical and subtropical regions, particularly in Africa and Nigeria, were prioritized. Review papers and meta-analyses were also included to enrich the synthesis with comprehensive and summarized evidence. Studies were excluded if they were not published in English, were duplicates, or lacked full-text access.

Results and Discussion

Insect frass is increasingly recognized for its rich nutrient profile and biological activity, making it a promising alternative to conventional fertilizers (Table 1). Studies have consistently shown that frass is a source of essential macro- and micronutrients, including nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), and trace elements (Beesigamukama *et al*., 2023). The nutrient composition varies depending on the insect species and the substrate used during insect rearing (Finke, 2013). For example, the frass of the black soldier fly (Hermetia illucens) contains moderate levels of nitrogen and phosphorus but is particularly rich in organic carbon, beneficial microbes, and chitinous residues (Lomonaco *et al*., 2024). The presence of chitin and microbial metabolites in frass contributes to soil biological activity, plant disease suppression, and stimulation of beneficial rhizobacteria (Beesigamukama *et al*., 2023; Lomonaco *et al*., 2024). These biological properties are particularly valuable for forest nurseries, where long-term soil health and microbial activity play critical roles in seedling establishment.

Table 1: Nutrient Composition of Common Insect Frass

Insect Species	Total Nitrogen (%)	Phosphorus (%)	Potassium (%)	Organic Carbon (%)	Other Notable Components	Reference
Black Soldier Fly (Hermetia illucens)	2.5 - 3.2	1.0 - 1.8	1.5 - 2.0	28 – 34	Chitin, Beneficial Microbes	Beesigamukama *et al*., 2023; Finke, 2013
Mealworm (Tenebrio molitor)	1.8 - 2.4	0.9 - 1.2	1.4 - 1.7	26 – 30	Chitin, Microbial Residues	Houben *et al*. (2020)

Cricket (Acheta domesticus)	2.1 - 2.8	1.1 - 1.5	1.6 - 1.9	27 – 31	Bioactive compounds	Ochieng'Ogaji *et al*., 2022

Multiple studies have demonstrated that the application of insect frass improves key soil properties, including nutrient availability, soil organic matter, and microbial biomass (Beesigamukama *et al*., 2023; Ochieng'Ogaji *et al*., 2022). Frass-amended soils typically show enhanced cation exchange capacity, improved aeration, and higher water-holding capacity, all of which are essential for healthy root development (Houben *et al*., 2020). The organic matter in frass improves soil structure and aggregation, creating a favorable environment for forest seedlings (Table 2). Importantly, frass has been reported to stimulate soil enzymatic activities such as dehydrogenase and phosphatase, contributing to nutrient mineralization and sustained soil fertility (Klammsteiner *et al*., 2020). These attributes make frass particularly suitable for nursery soils, which often require amendments that improve both physical and biological soil quality.

Table 2: Reported Effects of Insect Frass on Soil Properties

Soil Property	Reported Effect	Remarks	Reference
Soil Organic Matter	Increased	Improves soil aggregation and moisture retention	Ochieng'Ogaji *et al*., 2022
Cation Exchange Capacity	Enhanced	Improves nutrient holding capacity	Beesigamukama *et al.* (2023)
Soil Microbial Biomass	Increased	Stimulates beneficial rhizobacteria	Phurailatpam and Khwairakpam (2023)
Soil Enzymatic Activities	Elevated	Enhanced dehydrogenase and phosphatase activities	Beesigamukama *et al.* (2023)
Soil Structure	Improved	Better aeration, porosity, and root penetration	Houben *et al.* (2020)

While most available studies focus on food crops and horticultural species, the positive effects of insect frass on plant growth suggest potential applicability in forest nurseries. Frass application has been associated with increased germination rates, seedling height, root development, and biomass production in crops such as maize, tomato, lettuce, and kale (Poveda, 2021). In addition to providing nutrients, the bioactive compounds in frass appear to promote a balance between root and shoot growth and enhance resistance to pests and diseases. Although limited, some studies on tree species have shown improved early growth performance when grown in soils amended with frass (Mason *et al*., 2021). This evidence suggests that forest nurseries in Nigeria could benefit from incorporating insect frass into seedling production systems, particularly for native and multipurpose tree species.

Table 3: Effects of Insect Frass on Seedling Growth Parameters

Plant Type	Observed Effects	Indicator	Reference
Maize (Zea mays)	Higher biomass, improved root-shoot ratio	+18% Biomass	Poveda,(2021)
Tomato (Solanum lycopersicum)	Increased seedling height and disease resistance	+22% Height	Salomon *et al.* (2025)

Lettuce (Lactuca sativa)	Enhanced germination and leaf chlorophyll	+25% Germination	Houben *et al*. (2020)
Seedlings (Carrot)	Improved early growth and vigor	+15% Growth rate	Poveda,(2021)

Given the high demand for quality seedlings in Nigeria's forest restoration and afforestation programs, insect frass offers a sustainable and locally adaptable solution for enhancing nursery productivity. Organic fertilizers are already widely accepted in many forest nurseries due to their long-term benefits for soil health and low environmental impact. Frass can complement or substitute conventional organic amendments such as poultry manure and compost. Moreover, the growing insect farming industry in Nigeria, particularly black soldier fly farming, presents an opportunity to supply insect frass at scale to forestry stakeholders. Integrating frass into nursery practices could reduce reliance on costly synthetic fertilizers while contributing to soil health, seedling quality, and sustainability goals. However, empirical research is still needed to optimize frass application rates, blending ratios, and handling procedures specific to different Nigerian forest species.

Despite its potential, several challenges may limit the adoption of insect frass in forest nursery operations. First, the variability in frass composition due to differences in insect species, rearing substrates, and processing methods poses a challenge to standardizing fertilizer recommendations (Klammsteiner *et al*., 2023; Houben *et al*., 2020). Secondly, frass application rates suitable for forest tree species remain understudied, leading to uncertainty among practitioners. The presence of phytotoxic compounds, if frass is improperly processed, could negatively affect seedling performance. Additionally, acceptance among nursery managers may be limited by perceptions about the novelty and safety of insect-based inputs. Finally, logistical and economic considerations such as production scale, storage, and transport require further attention to make frass a mainstream nursery input in Nigeria.

Conclusion

The reviewed literature strongly supports the potential of insect frass as an eco-friendly and effective soil amendment for forest nursery operations. Insect frass is characterized by a balanced composition of essential plant nutrients, organic matter, beneficial microbes, and biologically active compounds, including chitin. Its application has consistently demonstrated improvements in soil fertility, structure, and microbial activity, resulting in enhanced seedling growth parameters, including germination rate, root development, and biomass accumulation. While most of the currently available evidence pertains to agricultural and horticultural crops, emerging studies suggest that similar benefits could be achieved for forest tree species. In the context of Nigeria, where forest degradation and reforestation efforts are gaining momentum, the integration of insect frass into forest nursery management could offer a sustainable, locally available, and cost-effective alternative to synthetic fertilizers. The growing insect farming sector, especially the production of black soldier fly frass, presents a timely opportunity to scale up the use of this biofertilizer. However, some challenges remain, including variability in frass composition, limited studies on forest species-specific responses, and technical gaps in application practices. Addressing these challenges will be critical for the widespread adoption of insect frass in forest nurseries.

Recommendations

For practical application, it is recommended that forest nursery managers in Nigeria begin to integrate insect frass into their nursery management practices. Frass can be used alone or in combination with other organic fertilizers, such as compost or poultry manure, to improve soil structure, enhance nutrient availability, and boost seedling performance. Since the product is relatively new to many forestry stakeholders, extension services and capacity-building programs should be organized to train nursery operators on proper frass handling, application methods, dosage, and storage. Creating

awareness about the safety and benefits of insect frass will also help improve its acceptance and adoption in forest nursery operations. From a research perspective, there is an urgent need for controlled studies that focus specifically on the forest tree species commonly used in Nigeria's forest restoration and afforestation programs. Research should target optimizing frass application rates, developing blending strategies with other organic materials, and standardizing quality assessment protocols for insect frass. Moreover, it is necessary to conduct long-term field trials to understand the effect of frass on seedling survival and growth after transplanting. In addition, socioeconomic studies are recommended to assess the cost-effectiveness, availability, and acceptance of insect frass among nursery managers and other forestry stakeholders.

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EFFECT OF PRE-GERMINATION TREATMENTS ON THE GERMINATION AND EARLY GROWTH PERFORMANCE OF *Acacia nilotica* IN FUDMA, KATSINA STATE

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ABSTRACT

Savanna trees play a significant role in the ecological balance of savanna ecosystems. However, their propagation is challenging due to low germination rates and slow growth. This research was conducted to assess the effectiveness of various pre-germination treatments on savanna tree seed germination and growth. The research was conducted at the Forest Nursery Unit of the Federal University, Dutsin-Ma. The experiment employed soaking, scarification, and stratification, as well as hot water techniques. The experiment was laid out as a 4 x 5 factorial in a Completely Randomized Design (CRD) with four replicates. Data analysis utilized ANOVA, and Duncan's Multiple Range was used to separate the means of differences among the treatments. Seeds treated with mechanical scarification were observed to start germinating 4 Days after sowing (DAS), followed by seeds treated with H2SO4 and water at room temperature, which started germinating 5 DAS. In contrast, untreated seeds and seeds treated with boiled water started germinating 7 DAS and 10 DAS, respectively. Significant differences were observed in germination rates. *Acacia nilotica* treated with Cold water and mechanical scarification yielded high germination (100% and 95%), followed by sulphuric acid, which had (90%). While hot water treatment resulted in a low germination rate (45%). Seedlings treated with mechanical scarification had higher heights (7.49 cm, 11.89 cm, and 14.87 cm; 2WAS, 4WAS, and 6WAS, respectively). Mechanical scarification resulted in increased stem diameter (0.22 and 0.24 mm; 4WAS and 6WAS). The findings highlight the effectiveness of pre-treatments, specifically cold water and mechanical scarification, in breaking seed dormancy for Acacia nilotica, essential for propagation success. We recommend implementing cold water treatment and mechanical scarification methods to break seed dormancy in Acacia nilotica seeds. These environmentally friendly methods offer valuable insights for the conservation and management of the savanna ecosystem.

Keywords: Savanna tree, Germination rate, Pre-treatments, *Acacia nilotica,* Seed dormancy

INTRODUCTION

Savanna trees play a significant role in the ecological balance of savanna ecosystems. However, their propagation is challenging due to low germination rates and slow growth. Pre-germination treatments such as soaking, scarification, and stratification have been shown to enhance the germination of tree seeds. The purpose of this study is to investigate the effect of different pre-germination treatments on the germination of savanna tree seeds in FUDMA, Katsina. Savanna trees are vital components of the savanna ecosystem, and their propagation is essential for maintaining ecological balance. Seed germination and early seedling growth phases are considered critical for raising a successful crop, as they directly determine the crop stand density and, consequently, the yield of the resultant crop (Hossain *et al*., 2005). It is indicated that seed germination, seedling growth, and survival percentage are governed by numerous intrinsic and extrinsic factors, and these factors are species-specific (Gunaga *et al.,* 2011*)*. Numerous trees have been identified as fast-growing and categorized as high biomass yielders. Many of these tree species have seeds with hard, impermeable seed coats, which prevents them from germinating under normal conditions (Dhupper, 2013). Therefore, studies on factors that affect germination, survival percentage, and seedling growth for a particular tree species are required. Pre-germination treatments such as soaking, scarification, and stratification have been shown to

enhance the germination of tree seeds. Seed is fundamental for regeneration (both artificial and natural), hence, without viable seeds whose dormancy has been overcome, tree establishment may not be possible (Oyebamiji *et al.,* 2014). It is worth noting that propagation through seeds is a relatively inexpensive method for establishing agroforestry trees (Oyebamiji *et al*., 2018a, b). Conscientious effort must be made to promote correct and adequate pre-germination methods for seeds, making them available as seedlings for re-afforestation and reclamation projects to meet both local and international demands (Oyebamiji *et al*., 2018c). Seed germination is the most important stage in a plant's life cycle. Water, air, temperature, and light are all essential for the seed germination process, starting from imbibition, activation, and succeeding manifestation. Germination speed is related to seedling vigor and can be a significant determinant of good field performance (Gebauer *et al*., 2002). Forest formations have always provided rural populations with various goods and services as well as substantial monetary income (Tyano *et al*., 2020). Faced with the magnitude of the challenge and to protect woody forest resources, the Ministry in charge of the environment and sustainable development has developed several techniques/technologies and strategies for the rehabilitation of degraded ecosystems, to satisfy the needs of the populations (Garba *et al*., 2020). These techniques or technologies aim to restore degraded lands, reconstitute vegetation cover, and improve the living conditions of populations by ensuring food security. However, the objectives targeted through these programs have not always been achieved, due to the absence of scientific planting programs for many native forest species of socio-economic importance, for several reasons, including low seed availability due to conservation problems, seed purity issues, and seed dormancy (Garba *et al*., 2020).

Forests provide multiple ecosystem services, spanning from local livelihoods and socio-economic development-related goods and services, such as food, wood, and water, to global ecological and economic services, including ecosystem functioning, biological diversity, carbon dynamics, and climate regulation. However, deforestation and forest degradation are causing a significant reduction in the provisioning of valuable ecosystem goods and services from forests in developing countries (Lundgren and Raintree, 2004). Seed is fundamental for regeneration (both artificial and natural); hence, without viable seeds whose dormancy has been overcome, tree establishment may not be possible (Oyebamiji *et al*., 2014). The study assesses the seed germination pattern and growth performance of *Acacia nilotica.* Understanding effective pre-germination treatments will inform strategies for conservation and management, ensuring the sustainability of savanna ecosystems. Enhancing germination rates and early growth performance will facilitate propagation, supporting reforestation and afforestation efforts. Successful propagation of *Acacia nilotica* will contribute to environmental conservation, climate change mitigation, and provide economic and social benefits to local communities and stakeholders involved in forestry and conservation, promoting sustainable livelihoods and environmental stewardship.

MATERIALS AND METHODS

STUDY AREA

The experiment was conducted in the nursery unit of the Department of Forestry and Wildlife Management, Federal University Dutsin-Ma, Katsina State, Nigeria. The area lies between latitudes 12º28'18.3" N and 07º29'15.4" E (Figure 1), with an annual rainfall of 700 mm, which is distributed from May to September. The mean annual temperatures range from 29 to 31 ºC. The high temperature normally occurs in April and May, and the lowest temperatures are typically found from December through February. The vegetation of the area is characterized by the Sudan savanna, which shares the characteristics and species of both the Guinea and Sahel savannas (Tukur and Kan, 2013).

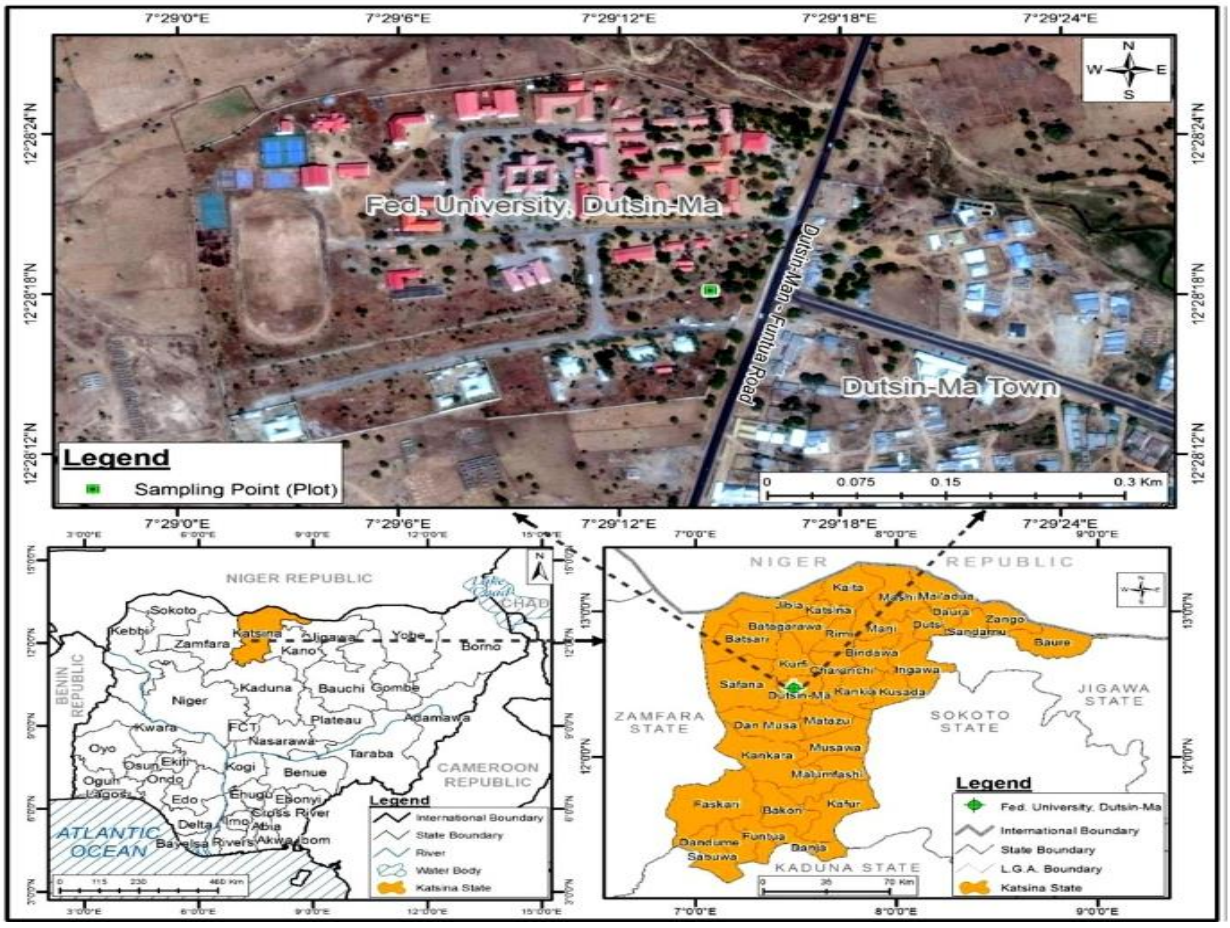

Figure 1: Map of the study Area

SEED PROCUREMENT

Seeds of *Acacia nilotica were purchased at the Wednesday market, Dutsin-ma,* Katsina State.

SEED VIABILITY TEST

The collected seeds were subjected to a viability test using the flotation method. All seeds that floated in water after a few minutes of soaking were considered unviable and discarded, while the seeds that sank were regarded as viable and used for further study (Omokhua *et al.*, 2015).

Collection of the Sowing Medium

The topsoil that was used as the sowing medium was collected from the upper level of the earth crust (0-15cm) at the Forestry Nursery Unit of the Federal University Dutsin-ma Katsina State. The topsoil was mixed with green yard manure at a ratio of 2:1. The soil was sieved and put in a poly pot.

Pre-germination Experiment

The seeds were subjected to different pre-germination treatments, including soaking in water at room temperature (T1), hot water treatment at 100°C (T2), mechanical scarification (T3), and Sulfuric acid scarification (T4). A control (T0) group with untreated seeds was also included in the experiment. For each pre-treatment, a total of 20 seeds were sown, making 100 seeds. Watering was done on a regular basis, to provide the containers with adequate moisture.

Procedures of pretreatments

Pretreatment procedures for Acacia nilotica seeds included five methods: Ambient Temperature Soaking (ANCW), where seeds were immersed in water at room temperature for 24 hours; Hot Water Treatment

(ANHW), where seeds were submerged in boiling water for 15 minutes; Sulphuric Acid Scarification (ANS), where seeds were treated with concentrated sulphuric acid for six minutes and thoroughly rinsed; Mechanical Scarification (ANMS), where the seed coat was partially removed using nail clippers; and Control (ANC), where untreated seeds were directly sown without any pretreatment, providing a baseline for comparison.

DATA COLLECTION

The germination rate, time of germination, and growth parameters, including total height, stem height, collar diameter, and leaf number, were monitored and recorded over a six-week period.

The total number of germinated seeds was counted from each treatment. Germination percentage (GP) was computed as follows (Zarchini *et al.,* 2011).

$$Seed\ germination\ \% = \frac{Total\ number\ of\ germinated\ seed}{Total\ number\ of\ seed\ sown} \times 100$$

Plant Height (cm): The height of the seedlings was measured from the root collar to the tip of the terminal shoot using a ruler in (cm).

Stem height: The height of the stems was measured from the root collar to the first branch.

Stem Diameter/collars (cm): The stem diameters were measured with the aid of a vernier caliper.

Days of Emergence: The first day for sprouting from each treatment was observed and recorded.

Number of Leaves: The number of leaves was counted and recorded.

Statistical Data Analysis

Data were analyzed using Analysis of Variance (ANOVA) with the Statistical Analysis System (SAS) computer package at a 5 % level of significance to determine differences in the treatment effect, while Duncan's Multiple Range test was used to separate the means of differences among the treatments.

RESULTS AND DISCUSSION

Days of Emergence

The first germination of Seeds treated with mechanical scarification was observed 4 days after sowing (DAS), that of seeds treated with concentrated (H_2SO_4) and cold water was observed 5DAS, and seeds treated with boiled water germinated 10DAS. In contrast, that of untreated seeds was observed 7 DAS (Figure 2). The germination of seeds under different treatments exhibited significant variation in the days to emergence (DTE). The earliest germination was observed in seeds treated with mechanical scarification, which emerged 4 days after sowing (DAS). It suggests that mechanical scarification effectively breaks the seed coat, allowing water and gases to penetrate more easily, thus accelerating the germination process.

Seeds treated with concentrated sulfuric acid (H_2SO_4) and cold water both germinated 5 DAS. The similar germination times for these treatments indicate that both methods are effective in breaking seed dormancy, although the mechanisms differ. Sulfuric acid likely breaks down the seed coat chemically, while cold water treatment may simulate natural environmental conditions that trigger germination.

Interestingly, seeds treated with boiled water took the longest to germinate, emerging 10 DAS. This delay could be due to the potential damage caused by high temperatures, which may have affected the seed's viability or delayed the germination process.

Untreated seeds germinated 7 DAS, which serves as a control to compare the effectiveness of the different treatments. The untreated seeds' germination time indicates the natural dormancy period without any intervention.

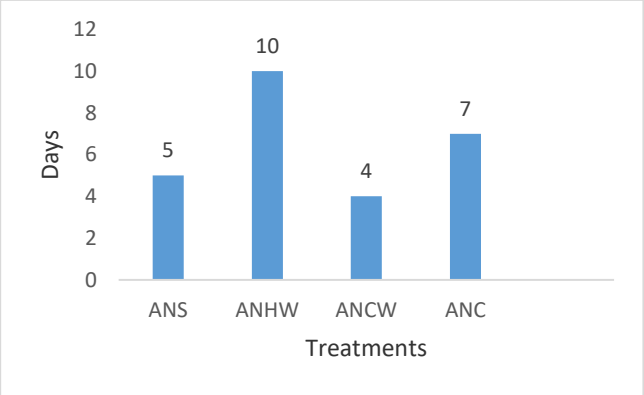

Figure 2: Effect of Pre-germination treatments on the day of germination

4.1.2 Germination Percentage (%)

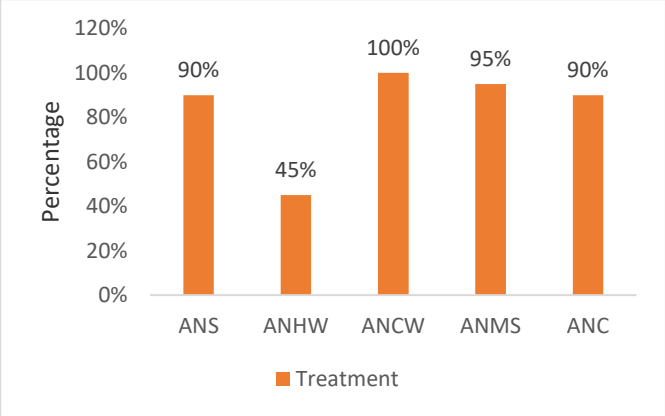

Figure 3: Effect of Pre-germination treatments on germination percentage.

Figure 3 results showed that seeds treated with cold water had the highest germination percentage (100%) and germinated 5 days after sowing (DAS). It is consistent with studies that highlight the effectiveness of cold-water treatment in breaking seed dormancy by simulating natural environmental conditions. For instance, research on cool-season grasses has shown that cold stratification can significantly enhance germination rates by mimicking winter conditions, which many seeds require to break dormancy (Baskin and Baskin, 2014).

Seeds treated with mechanical scarification in your study had a high germination percentage (95%) and emerged the earliest at 4 DAS. This method is widely recognized for its ability to break the seed coat physically, facilitating water uptake and gas exchange. Similar findings have been reported in studies on various plant species, where mechanical scarification has been shown to improve germination rates by overcoming physical dormancy (Bewley *et al*., 2013).

The 90% germination rate for seeds treated with concentrated sulfuric acid in your study aligns with other research that demonstrates the effectiveness of chemical scarification. Sulfuric acid treatment is known to chemically break down the seed coat, which can significantly enhance germination rates. For example, a study on *Triadica sebifera* found that chemical treatments, including sulfuric acid, effectively increased germination rates by breaking seed dormancy (Li *et al*., 2015).

The significantly lower germination rate (45%) for seeds treated with boiled water in your study suggests potential damage from high temperatures. This finding is supported by other research indicating that excessive heat can negatively impact seed viability. Studies have shown that while some heat treatments can be beneficial, boiling water often causes thermal damage to seeds, reducing their germination potential (Khan *et al*., 2012).

The 90% germination rate for untreated seeds in your study indicates a relatively high natural germination potential. It aligns with findings from other studies that suggest some seeds possess inherent dormancy-breaking mechanisms that can be activated under favorable conditions without any pre-treatment (Fenner and Thompson, 2005).

Plant height

The plant height results in Table 1 indicate that pre-sowing treatments significantly influenced plant growth throughout the experiment period. These findings can be related to existing literature on the effects of pre-sowing treatments on plant development.

At 2 weeks after sowing (WAS), plants treated with mechanical scarification were the tallest. This trend continued at 4WAS and 6WAS, where these plants remained among the tallest, statistically similar to those treated with sulfuric acid, cold water, and the control. Mechanical scarification is known to enhance seedling vigor by improving water uptake and gas exchange, which can lead to better early growth (Bewley *et al*., 2013).

At 4WAS and 6WAS, plants treated with sulfuric acid were among the tallest, similar to those treated with mechanical scarification, cold water, and the control. This aligns with research indicating that sulfuric acid treatment can effectively break seed dormancy and promote robust seedling growth by facilitating nutrient absorption (Li *et al*., 2015).

Plants treated with cold water also showed significant growth, being among the tallest at 4WAS and 6WAS. Cold water treatment can simulate natural stratification processes, enhancing seed germination and subsequent plant growth (Baskin and Baskin, 2014).

The untreated control plants showed similar growth patterns to those treated with mechanical scarification, sulfuric acid, and cold water at 4WAS and 6WAS. It suggests that the seeds have a high natural germination potential and inherent growth capabilities under favorable conditions (Fenner and Thompson, 2005).

Plants treated with boiled water consistently showed the shortest height at all stages (2WAS, 4WAS, and 6WAS). This significant reduction in growth can be attributed to potential thermal damage caused by the high temperature, which may impair seed viability and subsequent plant development (Khan *et al*., 2012).

Table 1: Effect of Pre-germination treatments on plant height.

	Plant Height		
Treatments	2WAS	4WAS	6WAS
SA	5.33[b]	10.97[a]	14.54[a]
HW	2.57[c]	5.36[b]	3.73[b]
CW	5.51[b]	10.10[a]	12.87[a]
MS	7.49[a]	11.89[a]	14.87[a]
C	4.80[b]	8.85[a]	10.91[a]
SE ±	0.36	1.14	1.44

Mean followed by the same letters within the same column and treatment are not significantly different at 5% level probability using Least Significant Difference (LSD) SE: Standard Error, SA; sulphuric Acid, Ms; Mechanical scarification, Hw: Seeds soaked in hot water at 100° C, CW; Seeds soaked in water at room temperature and C; control.

Stem height

The results from Table 2 indicate that there was a significant effect of pre-sowing treatments on stem height throughout the sampling period.

At 2WAS, plants treated with mechanical scarification, cold water, sulphuric acid, and control produced the tallest stems and were statistically similar, while plants treated with hot water produced the shortest stems and were significantly different. Recent studies have confirmed that mechanical scarification significantly improves germination and early growth in various plant species (Gbadamosi *et al*., 2021).

Similarly, at 4WAS plants treated with mechanical scarification, cold water, sulphuric acid, and control produced the tallest stems and were statistically similar. In contrast, seeds treated with hot water produced the shortest stems. Plants treated with boiled water consistently showed the shortest stem height at all stages (2WAS and 4WAS). This significant reduction in growth can be attributed to potential thermal damage caused by the high temperature, which may impair seed viability and subsequent plant development. Studies have demonstrated that excessive heat can negatively impact seed viability and reduce germination rates (Smith *et al*., 2021).

Table 2: Effect of Pre-germination treatments on stem height

	Stem Height		
Treatments	**2WAS**	**4WAS**	**6WAS**
SA	1.39[a]	1.55[ab]	2.02[a]

HW	0.80[b]	1.11[b]	0.95[b]
CW	1.45[a]	1.91[a]	2.28[a]
MS	1.86[a]	2.09[a]	2.14[a]
C	1.37[a]	1.77[a]	1.78[a]
SE (±)	0.15	0.20	0.22

Mean followed by the same letters within the same column and treatment are not significantly different at 5% level probability using Least Significant Difference (LSD) SE: Standard Error, SA; sulphuric Acid, Ms; Mechanical scarification, Hw: Seeds soaked in hot water at 100° C, CW; Seeds soaked in water at room temperature and C; control.

Collar Diameter

The collar diameter results table 3 study indicates that pre-sowing treatments significantly influenced collar diameter throughout the experiment period. At 2 weeks after sowing (WAS), plants treated with mechanical scarification, cold water, sulfuric acid, and the control produced the largest collar diameters, while plants treated with hot water had the smallest mean value. This trend continued at 4WAS and 6WAS, where plants treated with mechanical scarification, cold water, sulfuric acid, and the control maintained the largest collar diameters and were statistically similar. In contrast, plants treated with hot water consistently showed the smallest collar diameters, which were significantly different from those of the other treatments. These findings align with recent literature, which highlights the effectiveness of mechanical scarification, sulfuric acid, and cold-water treatments in promoting robust seedling growth and collar diameter (Gbadamosi *et al*., 2021; Khan *et al*., 2022; Li *et al*., 2023).

The detrimental effect of hot water treatment on collar diameter is consistent with studies showing that excessive heat can impair seed viability and reduce growth rates (Smith *et al*., 2021). The untreated control plants demonstrated high natural germination potential and growth capabilities, similar to those treated with mechanical scarification, sulfuric acid, and cold water (Fenner and Thompson, 2020). Overall, the results indicate that mechanical scarification, sulfuric acid treatment, and cold-water treatment are effective in promoting collar diameter growth, whereas hot-water treatment is detrimental. These findings highlight the importance of selecting suitable pre-sowing treatments to maximize plant growth and development.

Table 3: Effect of Pre-germination treatments on collar diameter

	Collar Diameter		
Treatments	**2WAS**	**4WAS**	**6WAS**
SA	0.18[a]	0.21[ab]	0.22[ab]
HW	0.10[b]	0.15[b]	0.13[b]
CW	0.19[a]	0.22[a]	0.23[ab]
MS	0.17[a]	0.22[ab]	0.24[a]
C	0.18[a]	0.20[ab]	0.22[ab]
SE (±)	0.01	0.02	0.03

Mean followed by the same letters within the same column and treatment are not significantly different at 5% level probability using Least Significant Difference (LSD) SE: Standard Error, SA; sulphuric Acid, Ms; Mechanical scarification, Hw: Seeds soaked in hot water at 100° C, CW; Seeds soaked in water at room temperature and C; control.

Number of leaves

The results from Table 4 show that there was a significant effect of pre-sowing treatment on the number of leaves throughout the experimental period.

At the 2WAS plant, those treated with mechanical scarification, sulphuric acid, and cold water produced the highest number of leaves and were statistically similar. It was followed by control, while the plant

treated with hot water produced the lowest number of leaves.

At 4WAS, the plant treated with mechanical scarification, sulphuric acid, cold water, and control produced the highest number of leaves and were statistically similar. In contrast, the plant treated with hot water produced the least leaf number and was significantly different from the rest.

Similarly, at the 6WAS plant, treated with cold water, mechanical scarification, and sulphuric acid, and control produced the highest number of leaves and were statistically similar, while the plant treated with hot water produced the smallest number of leaves and was significantly different. These findings are consistent with previous research demonstrating the positive effects of mechanical scarification (Harris *et al*., 2017), sulphuric acid (Kumar *et al*., 2018), and cold water (Lee *et al*., 2019) on seed germination and early seedling growth. In contrast, hot water treatment has been shown to inhibit seed germination and seedling growth (Garcia *et al*., 2020).

Table 4: Effect of pre-germination treatments on the number of leaves.

	Leaves Number		
Treatments	**2WAS**	**4WAS**	**6WAS**
SA	4.49^{ab}	10.41^{a}	10.75^{a}
HW	1.66^{c}	4.16^{b}	5.08^{b}
CW	4.33^{ab}	8.50^{a}	11.25^{a}
MS	5.33^{a}	10.75^{a}	11.16^{a}
C	3.41^{b}	8.50^{a}	10.08^{a}
SE (±)	0.44	1.02	1.32

Mean followed by the same letters within the same column and treatment are not significantly different at 5% level probability using Least Significant Difference (LSD) SE: Standard Error, SA; sulphuric Acid, Ms; Mechanical scarification, Hw: Seeds soaked in hot water at 100° C, CW; Seeds soaked in water at room temperature and C; control.

CONCLUSION AND RECOMMENDATION

Among the pre-sowing treatments employed, mechanical scarification, sulphuric acid treatment, and cold-water treatment resulted in faster germination. Seeds treated with cold water and seeds treated with mechanical scarification had the best germination percentage. The findings of this research, therefore, conclude that cold water treatment and mechanical scarification are the best pre-sowing treatments for breaking seed dormancy for *Acacia nilotica.* Future work in this area can be improved by reducing the temperature of the hot water. When removing or reducing the seed coat, proper care should be taken to avoid damaging the embryo. The implementation of cold-water treatment and mechanical scarification methods for breaking seed dormancy in Acacia nilotica offers a valuable, environmentally friendly approach for enhancing seed germination. These methods offer a sustainable and effective solution for promoting seedling establishment, a crucial step in the conservation and management of savanna ecosystems. By adopting these eco-friendly techniques, we can promote the regeneration of Acacia nilotica, a key species in maintaining the ecological balance of savannas, while minimizing the environmental impact of traditional seed treatment methods.

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Theme: *Forest Sustainability in the face of climate change and insecurity: Innovative technologies and Strategies*

IN SITU CONSERVATION OF *PTEROCARPUS ERINACEUS* (AFRICAN ROSEWOOD) IN AHMADU BELLO UNIVERSITY, ZARIA, NIGERIA

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ABSTRACT

Pterocarpus erinaceus, commonly known as African Rosewood, is a valuable hardwood and endangered tree, native to West Africa. However, overexploitation of this species has led to a drastic decline in its population, resulting in its listing as endangered by the International Union for Conservation of Nature (IUCN). The study was carried out at Ahmadu Bello University, Zaria, with the aim of promoting in-situ conservation of Pterocarpus erinaceus. To this goal, structured questionnaires were administered to 40 respondents randomly selected from residents within the study area. Thirty (30) stands of *Pterocarpus erinaceus* were identified in 6 different locations within the study area, all of which were measured with six (6) stands from each sampling unit. The diameter at breast height (D.B.H.) was taken using a diameter tape, while the height of the identified stands of Pterocarpus erinaceus was measured using a Haga Altimeter. The geo-locations of the selected species were measured using a hand-held Global Positioning System (GPS) device. The results from the study indicated that *Pterocarpus erinaceus* exists naturally within the institution as indicated in the GPS mapping of 5 locations with 30 stands of the species identified. It also revealed that the majority of the respondents (70%) use the bark for medicinal purposes. Parts of the constraints identified include a lack of extension support services, fire outbreaks, debarking of trees, and harvesting for fuelwood and charcoal production, as well as the production of seedlings of the species for reforestation and sustainability. To ensure the sustainability of the species, it was recommended that the University establish protected areas, restore degraded habitats, and control illegal logging of *Pterocarpus erinaceus* in the study area.

Key words: In situ conservation, *Pterocarpus erinaceus, Ahmadu Bello University*

Introduction

African rosewood (*Pterocarpus erinaceus* Poir) is a high-value woody species belonging to the Fabaceae family. The tree is endemic to the Guineo-Sudanian and Sudano-Sahelian zones, where natural stands are under constant pressure due to over-exploitation for its timber (Adjonou *et al*., 2020). The tree is also used as a source of wood fuel, fodder, in fabric dyeing, and for traditional medicines (Dumenu and Bandoh, 2016; Rabiou *et al*., 2017). Being heavily exploited in a range of countries across West Africa. Rosewood has been classified as endangered with a declining population (IUCN, 2018; CITES, 2017). In addition, several countries have imposed a ban on felling and exporting rosewood timber (Adjonou *et al*., 2020). These efforts are geared towards ensuring the long-term sustainability of the species.

It is distributed throughout the West and Central African savanna and dry forest. It is popularly known as 'African rosewood'. In northern Nigeria, it is called "Madobiya" or "Shajini", while in the south, it is called "Apepe" or "Osun dudu". A mixture of the stem bark is used as an astringent for severe diarrhea and dysentery. In some parts of Kano in Northern Nigeria, its decoction is used orally to arrest bleeding (Khamis Sangarib, verbal communication).

Pterocarpus erinaceus Poir is among those polyvalent species listed as endangered on the International Union for Conservation of Nature (IUCN) Red List (Barstow, 2018). It has also been listed on CITES Appendix II since 2016. It is quite threatened throughout its distribution range because the wood has a higher trade value (Dumenu, 2019; EIA, 2017).

In West Africa, the demise of rosewoods contributes to overall deforestation and degradation threats facing the Guinean-Sudano-Sahel ecosystems from 2010 to 2015 (CITES, 2016), Chinese imports of *Hongmu* logs from West Africa soared from 2,788 m3, worth US$1.1 million (2009/2010), to 387,334 m3, worth US$ 264 million (2015). *Pterocarpus erinaceus* dominated this 500-fold increase by value and volume. It put enormous pressure on the genus and overall species diversity. The primary objective of this study is to promote in-situ conservation of Pterocarpus erinaceus within Ahmadu Bello University, Zaria, Nigeria**.**

Materials and Methods

Study Area

Ahmadu Bello University, Zaria, Kaduna state, Nigeria was founded in 1962 from 3 previously independent institutions; the Nigerian college of Arts, science and technology, Institute of Administration in Tudun Wada area of Zaria, and the Regional Research Station of the Ministry of Agriculture now the Institute for Agricultural Research Ahmadu Bello University, though situated in Samaru, Zaria in the Sabon Gari Local Government Area of Kaduna State. It is located on latitude 11° 15'N to 11°3'N of the equator and longitude 7° 30'E to 7°45'E of the Greenwich Meridian.

Sampling Techniques/Data Collection

A two (2) stage sampling technique was employed for data collection in this study. The first stage involved the use of self-administered structured questionnaires. A total of 40 respondents were purposively sampled in 5 locations where *Pterocarpus erinaceus* were found in the study area, with eight respondents per location. The second stage involved the physical identification of *Pterocarpus erinaceus* in its natural habitat within the study area, while its geo-location was recorded with the aid of a Global Positioning System (GPS). The girths of the identified trees were subsequently measured in Diameter at Breast Height (DBH), while their heights were also recorded.

Table 1: Locations where *Pterocarpus erinaceus* were found in ABU Zaria

S/N	Location	No of Respondents	Percentage
1	Area BZ	8	20
2	Area C	8	20
3	Area F	8	20
4	Area G	8	20
5	Savanna Quarters	8	20
	Total	**40**	**100**

Source: Field Survey 2023

Figure 1: Map of ABU Zaria showing sampling locations

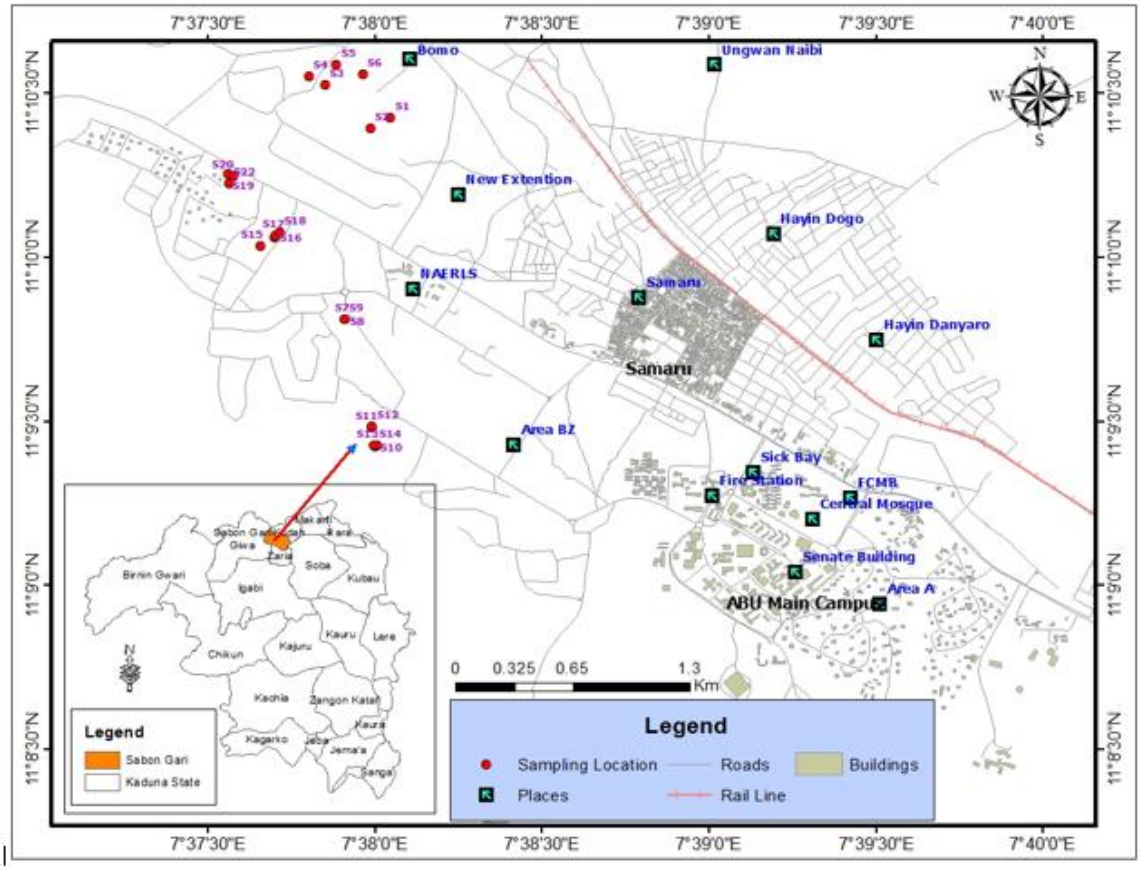

Figure:1. Map of ABU Zaria Showing Sampling Location.

Source: GIS Lab Department of Geography ABU Zaria, Using Arc GIS 10.3 Software.

Table 2: Identification and Awareness of the Species

VARIABLES	YES	NO	MEAN
Able to identify the *Pterocarpus erinaceous* tree	36 (90)	4 (10)	1.10
Aware of its economic importance	34 (85)	6 (15)	1.15
Awareness of the location(s) of *Pterocarpus erinaceus* within Ahmadu Bello University	25 (62.5)	15 (37.5)	1.38

Source: Field Survey 2023 (note: multiple responses)

The majority of the respondents (90%) can identify the species, 85% are aware of its economic importance, while 15% are not familiar with its economic importance. It signifies that the majority of

the respondents can identify and are aware of the species' economic importance. The majority of the respondents (62.5%) are aware of the species' location within the study area.

Table 3: Plant height of *Pterocarpus erinaceous* as influenced by location

Location	**Plant height (m)**
Beside the University Staff School, Area BZ	7.9b
Beside I.A.R Nursery, Area C	14.5a
Department of Crop Protection	13.2a
Along Sokoto Road, Area G	9.9b
Savanna Quarters	9.2b
SE±	0.643
Significance	**
CV (%)	14.4

Means followed by the same letter(s) within the same treatment column are not different statistically at the *P=0.05* level of probability using DMRT

**= F-value significance at (P≤0.01)

Table 3 above shows the data collected and analyzed regarding the plant height of Pterocarpus erinaceous at different locations within Ahmadu Bello University, Zaria. It was revealed that the trees with the highest heights are those located beside the I.A.R. nursery in Area C, with a a mean value of 14.5m. It is probably due to the trees having been naturally established in this location for a longer period. *P. erinaceus located around the Department of Crop Protection has the second-highest total height mean Value, which is not statistically different from Area C and the Crop Protection Department, while Area G, Savanna Quarters,* and Area BZ are not statistically different. Area BZ has the lowest mean height as a result of excessive exploitation around the axis.

Figure 2: Graph Showing *Pterocarpus erinaceus* Heights and their Locations in the Study Area

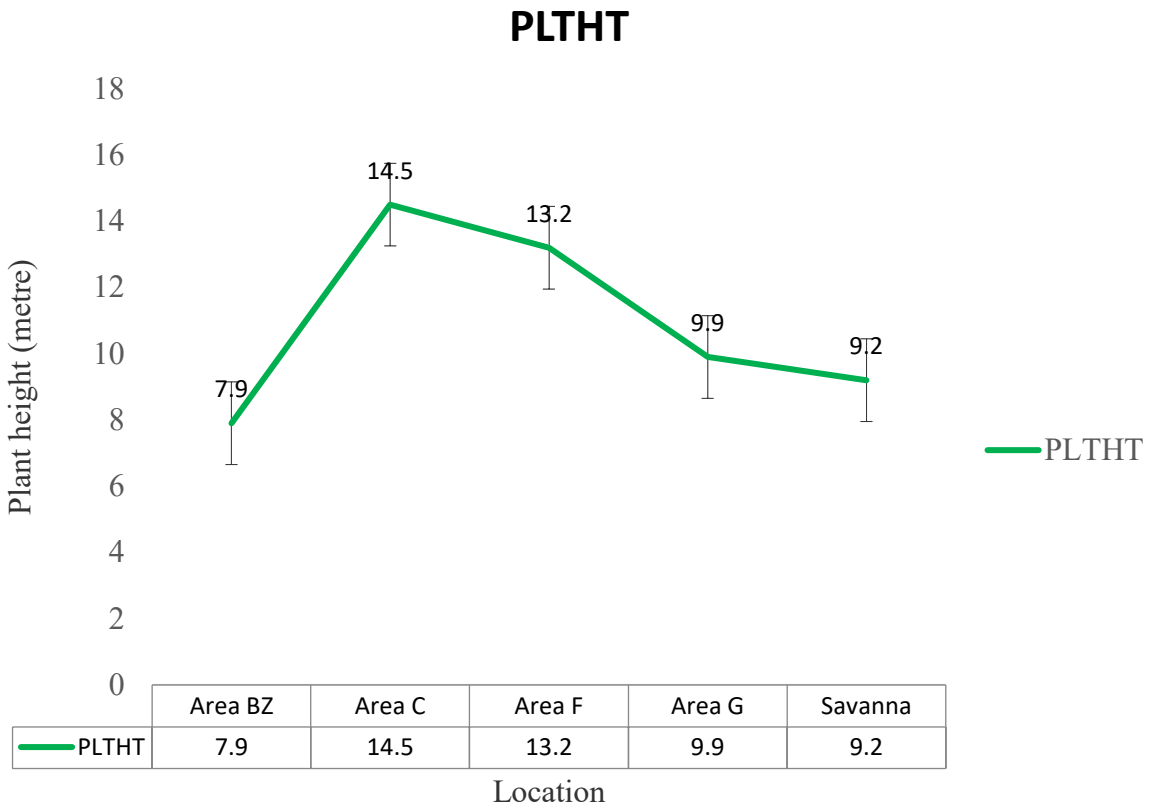

Table 4: Girth of *Pterocarpus erinaceous* as influenced by location in the Study Area

Location	**Tree girth (m)**
Beside the University Staff School, Area BZ	0.39c
Besides I.A.R Nursery, Area C	1.40a
Department of Crop Protection	0.84b
Along Sokoto Road, Area G	1.00b
Savanna Quarters	0.95b

SE±	0.118
Significance	**
CV (%)	31.5

Means followed by the same letter(s) within the same treatment column are not different statistically at the *P=0.05* level of probability using DMRT

**= F-value significance at (P≤0.01)

From Table 4 above, it can be observed that area BZ recorded the lowest value of stem girth, which may be due to the younger trees of P. erinaceus receiving more silvicultural attention, such as constant weeding and fire tracing, due to their proximity to residential quarters. Area C recorded the highest value of stem girth, likely due to its large size, silvicultural practices, and possibly its old age.

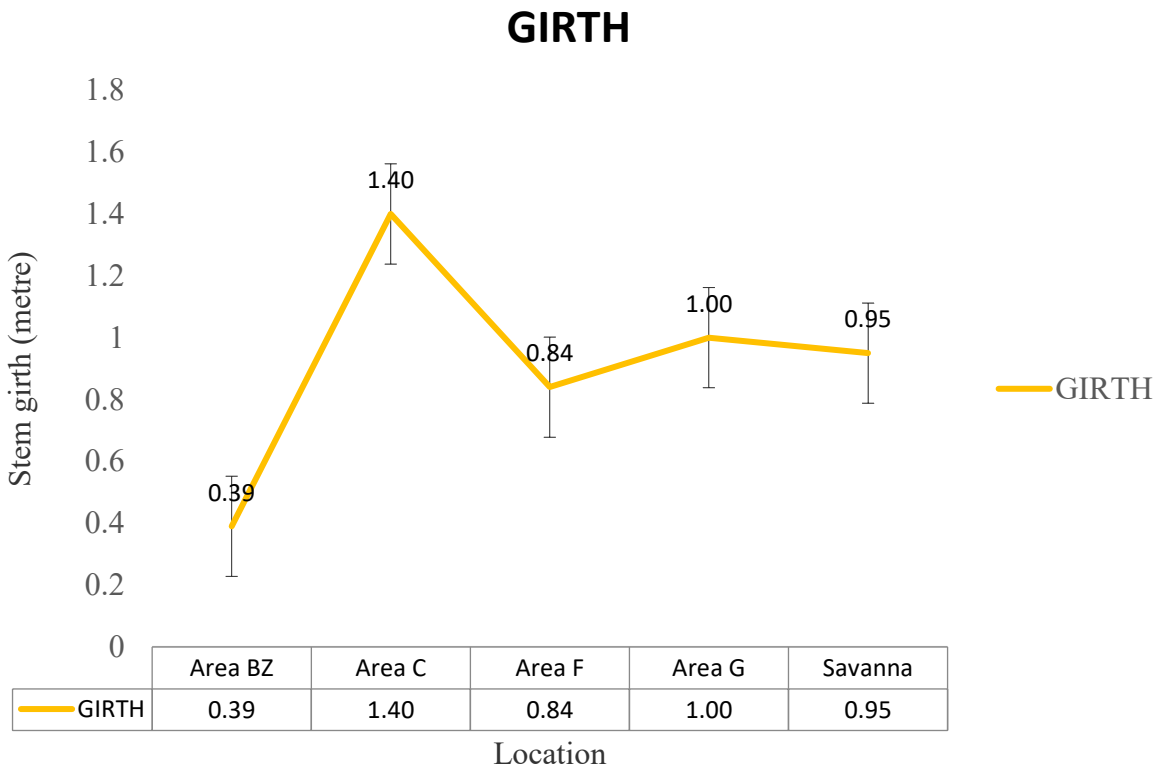

Table 5: Distribution of respondents according to constraints faced regarding the tree's sustainability in the Study area

S/N	Constraints	Very Severe (%)	Severe (%)	Less Severe (%)	Not Severe (%)	Rank

1	Debarking and harvesting of *Pterocarpus erinaceus* and other parts for medicinal purposes	75.0	20.0	5.0	-	1st
2	Harvesting for fuelwood and charcoal production	60.0	25.0	10.0	5.0	2nd
3	Fire outbreak	40.0	30.0	20.0	10.0	3rd
4	Illegal logging for timber	30.0	30.0	25.0	15.0	4th
5	Cultural inclination as regards the tree	25.0	10.0	20.0	45.0	5th

Source: Field Survey 2023

The table above reveals that the major constraint militating against the sustainability of Pterocarpus erinaceus in the study area is the debarking and harvesting of its parts for medicinal purposes, which ranked the highest, while cultural inclination about the species ranked the lowest. Other constraints identified include harvesting for fuelwood and charcoal production, fire outbreaks, and illegal logging for timber.

Conclusion and Recommendations

Conclusion

The study concluded that *Pterocarpus erinaceus,* which exists naturally within Ahmadu Bello University, is being threatened due to selective exploitation through debarking for medicinal purposes, fire outbreaks, and illegal logging.

Recommendations

1. The Management of Ahmadu Bello University should ensure that areas where *Pterocarpus erinaceus* occur naturally within the campus are protected through the deployment of forest guards.
2. Owing to the enormous socio-economic potentials of P. erinaceus, Ahmadu Bello University and other research-based Institutions should commence research work on the reduction of the species' gestation period for domestication purposes.
3. There is a need to raise a large population of *P. erinaceus* seedlings for distribution to farmers in and around the study area, as well as for plantation establishment, which will ensure the sustainability of the species by the University and other stakeholders, such as Research institutions and ADPs.
4. There is a need to ensure the prevention of fire incidents around areas where Pterocarpus erinaceus is found in the study area.
5. All tiers of Government, including the University, should embark on an enlightenment campaign programme to further educate the people and other critical stakeholders on the vast economic importance of Pterocarpus erinaceus, as well as the need for its sustainability.

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JUVENILE GROWTH RESPONSE OF NONI (*Morinda citrifolia* L.) TO ORGANIC AND INORGANIC FERTILIZERS

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ABSTRACT

A study was conducted in the greenhouse of the Soil and Tree Nutrition Department at the Forestry Research Institute of Nigeria, Ibadan (FRIN), to investigate the growth response of Morinda citrifolia to varying levels of Aleshinloye compost and N:P:K 15:15:15 in a degraded Alfisol under tropical Nigerian environmental conditions. The study was laid out in a completely randomized design (CRD) with twelve (12) treatments replicated six (6) times, making a total of seventy-two (72) experimental units. Data collected include Stem Girth (mm), plant height (cm), and Number of leaves starting from 30 Days After Transplanting (DAT). The result revealed that the soil sample used for this study had a pH value of 6.06 and a a total N value of 0.11%. Noni plant with treatment T11 (N:P: K 15:15:15 at 80 Kg Nha^{-1} + Aleshiloye compost (AC) at 80 Kg Nha^{-1}) had the highest plant height values of 48.17, 65.67 and 77.87 cm respectively which are significantly higher (P= .05) than T1 (control) with 37.17, 47.50 and 55.33 cm respectively that are the least values observed from 120 DAT to 180 DAT. Plant Dry Matter (PDM) for leaves, stem, and root (3.593, 2.720, and 4.220 g/ g/plant), respectively, from the control (T1) plant was the least when compared to every other treatment in the study. The use of composted manure in combination with N:P: K 15:15:15 ensured an early and continuous supply of nutrients, resulting in higher growth performance of Noni over six months.

Keywords: *Compost, Fertilizer, Growth response, Morinda citrifolia, and Soil.*

INTRODUCTION

Morinda citrifolia L., commonly known as Noni, grows widely throughout the Pacific and is one of the most significant sources of traditional medicine among Pacific island societies. It is a fruit species of the Rubiaceae family that produces fruits throughout the year during its productive stage in all its branches (Cavalcante *et al.,* 2014; Kumar and Ponnuswami, 2014). Noni has a rooting habit similar to that of citrus and coffee, with an extensive lateral root system and a deep taproot.

Due to the paucity of information, noni nutritional requirements are estimated using coffee trees (Coffea arabica) as a reference, given that both belong to the same family (Cavalcante et al., 2014; Silva et al., 2014). Noni cultures positively respond to the

application of organic matter to the soil, such as cattle manure, resulting in nutritionally balanced plants and fruits with adequate post-harvest quality (Kumar and Ponnuswami, 2014; Silva et al., 2014; Souto et al., 2016). As reported by Nyamangara *et al.* (2003), the management of soil organic matter through the use of composted organic waste is key to sustainable agriculture. Increasing soil organic matter has the added benefit of improving soil quality and thereby enhancing the long-term sustainability of agriculture (Laird *et al.,* 2001). Among the practices recommended for improving soil quality and fertility in tropical regions is the application of composted organic waste, which slowly releases significant amounts of nitrogen and phosphorus (Eghball *et al.,* 2001).

International research has shown that municipal compost can be beneficial as both a soil conditioner and a slow-release nutrient source (Sullivan et al., 2016). Since the establishment of adequate levels of nutrients is necessary to assist fertilization and nutritional requirement for noni cultivation plans (Silva *et al.,* 2014, Souto *et al.,* 2016), this study aims to investigate the early growth response of *Morinda citrifolia* L to varying levels of Aleshinloye compost and N:P: K 15:15:15 in a degraded Alfisol in a tropical Nigerian environmental condition.

MATERIALS AND METHODS

2.1 Study Location

The study was carried out in the greenhouse of the Soils and Tree Nutrition department of the Forestry Research Institute of Nigeria, Ibadan (FRIN). The study site is located on longitude 07°23'18" N to 07°23'43" N and latitude 03°51'20" E to 03°23'43" E. The climate of the area is characterized by a West African monsoon, featuring distinct dry and wet seasons. The mean maximum temperature of the area during the study period was 31.11°C, with a minimum of 22.76 °C, while the mean daily relative humidity was approximately 71.8% (FRIN, 2019).

2.2 Soil Collection and Preparation

The degraded topsoil used for the experiment was collected within the the FRIN Arboretum. The soil was air-dried and passed through a 2 mm diameter sieve before 3 kg of soil was filled into polythene pots of 15 cm x 20 cm dimensions. A subsample of the soil was taken to the Laboratory of Soils and Tree Nutrition, Department of the Institute, for determination of both physical and chemical properties.

2.3 Soil and Compost Analysis

The soil pH was determined with the pH meter (SM-3H Microfield England) using a glass electrode in a 1:2 soil-to-water ratio. The organic carbon content of the soil was determined using the Walkley-Black wet oxidation method. Total nitrogen was determined using the micro-*Kjeldahl* method. Available P was determined using the Bray-1 method. A sub-sample was also extracted with ammonium acetate, and the solution was filtered using Whatman No. 1 filter paper. The extract was then analyzed using a a flame photometer to determine its sodium and potassium contents. The concentrations of calcium and magnesium in the extract were determined using an Atomic Absorption Spectrophotometer (AAS). Likewise, another subsample of the soil was extracted with 1 N HCl for the determination of Iron, Copper, Zinc, and Manganese concentrations using AAS. A sample of the organic fertilizer (Aleshinloye compost) was also digested with a combination of nitric and perchloric acid, and the digest was analyzed for essential plant nutrient concentrations.

2.4 Experimental Design

The study was laid out in a completely randomized design (CRD) with twelve (12) treatments replicated six (6) times with a total of seventy-two (72) experimental units. The treatments are: T1 (Control), T2 (Aleshinloye compost (AC) at 80 Kg Nha^{-1}), T3 (AC at 160 Kg Nha^{-1}), T4 (AC at 240 Kg Nha^{-1}), T5 (N:P: K 15:15:15 at 80 Kg Nha^{-1}), T6 (N:P: K 15:15:15 at 40 Kg Nha^{-1} + AC at 40 Kg Nha^{-1}), T7 (N:P: K 15:15:15 at 40 Kg Nha^{-1} + AC at 80 Kg Nha^{-1}), T8

(N:P: K 15:15:15 at 40 Kg Nha^{-1} + AC at 120 Kg Nha^{-1}), T9 (N:P: K 15:15:15 at 160 Kg Nha^{-1}), T10 (N:P: K 15:15:15 at 80 Kg Nha^{-1} + AC at 40 Kg Nha^{-1}), T11 (N:P: K 15:15:15 at 80 Kg Nha^{-1} + AC at 80 Kg Nha^{-1}) and T12 (N:P: K 15:15:15 at 80 Kg Nha^{-1} + AC at 120 Kg Nha^{-1}). The organic fertilizer was applied 4 weeks before transplanting, while the inorganic fertilizer was applied 2 weeks after transplanting, and pre-germinated seedlings of Noni were transplanted at the four-leaf stage.

2.5 Data Collection

The data collected include stem girth (mm), plant height (cm), and the Number of leaves starting from 30 days after transplanting (DAT), which were also repeated at 4-week intervals. Plant dry matter was obtained at the 180th DAT. The Number of leaves was determined through physical counting of the leaves per plant. The plant height was measured from the soil surface with the aid of a meter rule, while the diameter at breast height was measured using a Venire caliper and recorded in millimeters. The plant was harvested at 180 DAT and gently rinsed in clean water before separating into leaves, stems, and root parts. These parts were oven-dried at 650 °C until a constant weight was recorded for the plant Dry matter (g/plant) for the stem, root, and leaf portions of the seedlings at the end of the experiment.

2.6 Statistical Analysis

The data collected were subjected to statistical analysis of variance (ANOVA) using GenStat software, 9th Edition. Significantly different means were separated using the Duncan Multiple Range Test (DMRT) at a 5% probability level.

3. RESULTS AND DISCUSSION

3.1 Soil and Compost Properties

The result revealed that the soil sample used for this study had a pH value of 6.06 and a total N value of 0.11% which is classified as low (Blakemore *et al.,* 1987). The available P value was 2.12 mg/kg, Exchangeable bases; K^+, Na^+, Ca^{2+} and Mg^{2+} had the values of (0.13, 0.38, 3.61 and 2.00) $cmol^+$ kg^{-1}, respectively which according to (FAO *et al.,* 2004) are in a very low critical range except for Ca^{2+} that is low. The micro-nutrients, Mn^{2+}, Fe^{2+}, $Cu^{2+,}$ and Zn^{2+} had the values of (57.7, 20.8, 10.5, and 16.9) mg kg^{-1}, respectively (Table 1). The proportions of sand, silt, and clay were 836, 96, and 68 g kg-1, respectively. The nutrient composition of the compost used was generally high, and it had a pH value of 7.03, which is neutral (Table 1).

3.2 Plant Height (cm)

The application of organic and inorganic fertilizers had no significant effect (*P*=.05) on Noni plant height at 30 days after transplanting (DAT). However, at 60DAT, the combination of N:P: K 15:15:15 at 40 Kg Nha^{-1} + AC at 40 Kg Nha^{-1} (T6) significantly influence Noni plant height with recorded 9.85 cm that was significantly higher than those of treatments T1 (control) (7.77 cm) and T2, T3 and T4 (7.97, 7.98 and 7.90 cm) respectively which were solely organic fertilizer. This result supports previous international research indicating that municipal compost can be beneficial as both a soil conditioner and a slow-release nutrient source (Sullivan *et al.,* 2016; Sullivan *et al.,* 2003). At 90DAT, plant height with treatment T12 (N:P: K 15:15:15 at 80 Kg Nha^{-1} + AC at 120 Kg Nha^{-1}) recorded a significantly higher value (26.07 cm) compared to those of T1 (control) (19.67 cm) and T2, T3 and T4 (21.25, 21.25 and 19.75 cm) respectively (Table 2). Similarly, from 120DAT to 180DAT, Noni plant with treatment T11 (N:P: K 15:15:15 at 80 Kg Nha^{-1} + AC at 80 Kg Nha^{-1}) which consisted the recommended rate (160 Kg Nha^{-1}) for coffee production which belongs to the same family (Rubiaceae) with Noni (Cavalcante *et al.,* 2014, Silva *et al* 2014) had the highest values of 48.17, 65.67 and 77.87 cm respectively which were significantly higher than T1 (control) with 37.17, 47.50 and 55.33 cm respectively that were the least values observed from 120 DAT to 180 DAT (Table 2)

3.3 Plant Stem Girth (mm)

The response of Noni plant stem girth to different soil treatments in this study revealed a significant difference at P = 0.05 from 30 days after treatment (DAT).The highest value (1.657 mm) recorded at this period was from plant with treatment T8 (N:P: K 15:15:15 at 40 Kg Nha^{-1} + AC at 120 Kg Nha^{-1}) while the least value (1.272 mm) was that of plant from T6 (N:P: K 15:15:15 at 40 Kg Nha^{-1} + AC at 40 Kg Nha^{-1}) (Table 3). It was in line with (Nyamangara *et al.,* 2003) who reported that organic waste (composted manure) application enhanced the use efficiency of mineral N fertilizer by crops when the two were applied in combination. The T6 combination does not meet the recommended rate (160 Kg Nha-1) for coffee production (Cavalcante et al., 2014; Silva et al., 2014), which could be responsible for the minimal increase in Noni stem diameter. From 90DAT to 150DAT, the stem diameter of Noni plant with treatment T12 (N:P: K 15:15:15 at 80 Kg Nha^{-1} + AC at 120 Kg Nha^{-1}) recorded the highest stem diameters of 4.667, 7.973 and 9.573 mm respectively and was significantly higher than that of control (T1). Those of T2, T3 and T4 (Organic fertilizers) values recorded from 90 DAT to 150DAT (Table 3). At the end of the study (180DAT), the Noni plant with treatment T11 (N:P: K 15:15:15 at 80 Kg Nha^{-1} + AC at 80 Kg Nha^{-1}) also recorded the highest stem diameter (11.34 mm) value which is significantly higher than those of control (T1) and T2 (AC at 80 Kg Nha^{-1}) (8.24 and 9.34 mm) respectively (Table 3). This is similar to the results obtained for plant height in this study and can also be attributed to the enhanced use efficiency of mineral N fertilizer by crops when organic and inorganic fertilizers are combined (Nyamangara *et al.,* 2003), Organic fertilizers application alone are expected to be slow nutrient releasing as evident in results obtained from T2, T3 and T4.

Table 1. Pre-planting soil and compost chemical and physical properties

Properties	Soil	Compost
pH (H2O, 1:2)	6.06	7.03
Organic C (g/kg)	11.0	109.7
Total N (g/kg)	1.10	20.8
Available P (mg/kg)	2.12	15.5
K (Cmol/kg)	0.13	2.1
Ca (Cmol/kg)	3.61	7.4
Mg (Cmol/kg)	2.00	10.0
Na (Cmol/kg)	0.38	1.2
Fe (g/kg)	57.7	185
Mn (mg/kg)	20.8	60.7
Zn (mg/kg)	10.5	29.0
Cu (mg/kg)	16.9	10.6
Sand (g/kg)	836	
Clay (g/kg)	96	
Silt (g/kg)	68	
Textural class	Loamy sand	

Table 2. Effect of organic and inorganic fertilizers on the early growth performance of Noni plant height (cm)

Treatment	30 DAT	60 DAT	90 DAT	120 DAT	150 DAT	180 DAT
T1	3.48^{a}	7.77^{bc}	19.67^{c}	37.17^{d}	47.50^{e}	55.33^{c}
T2	3.70 ^{a}	7.97^{bc}	21.25^{c}	39.67^{cd}	50.67^{de}	63.67^{bc}
T3	3.37 ^{a}	7.98^{bc}	21.42^{c}	43.17^{abcd}	53.00^{cde}	64.08^{bc}
T4	3.52 ^{a}	7.90^{bc}	19.75^{c}	40.83^{bcd}	54.18^{cde}	65.30^{b}
T5	3.45 ^{a}	8.00^{bc}	21.92^{c}	45.50^{abc}	55.08^{cde}	68.00^{ab}
T6	3.93 ^{a}	9.85^{a}	25.37^{ab}	47.50^{ab}	57.67^{bcd}	67.92^{ab}
T7	3.75 ^{a}	7.72^{bc}	20.00^{c}	44.33^{abc}	56.75^{bcd}	68.82^{ab}
T8	4.08 ^{a}	9.18^{ab}	22.83^{abc}	45.67^{abc}	59.58^{abc}	71.67^{ab}
T9	3.47 ^{a}	7.65^{c}	22.90^{bc}	46.50^{ab}	58.83^{abc}	71.75^{ab}
T10	3.38 ^{a}	7.83^{bc}	22.62^{bc}	48.75^{a}	63.33^{ab}	76.72^{a}
T11	3.30 ^{a}	8.17^{bc}	22.48^{bc}	48.17^{a}	65.67^{a}	77.87^{a}
T12	3.93 ^{a}	9.03^{abc}	26.07^{a}	47.08^{ab}	60.17^{abc}	70.12^{ab}

Means value within a column followed by the same letter(s) are not significantly different at P=.05

Table 3. Effect of organic and inorganic fertilizers on the early growth performance of the Noni plant stem girth (mm)

Treatment	30 DAT	60 DAT	90 DAT	120 DAT	150 DAT	180 DAT
T1	1.437^{abc}	1.538^{cd}	2.872^{f}	5.965^{e}	6.728^{e}	8.24^{d}
T2	1.643^{a}	1.493^{d}	3.117^{f}	5.693^{e}	7.353^{de}	9.34^{cd}
T3	1.565^{ab}	1.597^{bcd}	3.197^{ef}	6.702^{cde}	7.923^{cd}	10.17^{abc}
T4	1.523^{abc}	1.557^{cd}	3.020^{f}	6.300^{de}	7.623^{d}	9.60^{bc}
T5	1.317^{bc}	1.518^{cd}	3.397^{def}	7.848^{ab}	8.538^{bc}	10.92^{ab}
T6	1.272^{c}	1.918a	4.318^{ab}	7.72^{abc}	8.877^{ab}	10.69^{ab}
T7	1.643^{a}	1.788^{ab}	3.482^{cdef}	6.695^{bcde}	7.892^{cd}	10.05^{abc}
T8	1.657^{a}	1.722^{abc}	4.205^{abc}	7.258^{abcd}	8.650^{bc}	10.82^{ab}
T9	1.522^{abc}	1.640^{bcd}	3.893^{bcde}	7.233^{abcd}	8.727^{abc}	10.25^{abc}
T10	1.585^{ab}	1.713^{abcd}	3.870^{bcde}	7.640^{abc}	9.063^{ab}	10.75^{ab}
T11	1.587^{ab}	1.678^{bcd}	4.053^{abcd}	7.658^{abc}	9.565^{a}	11.34^{a}
T12	1.577^{ab}	1.797^{ab}	4.667^{a}	7.973^{a}	9.573^{a}	10.93^{ab}

Means value within a column followed by the same letter(s) are not significantly different at P = .05

3.4 Number of Leaves

At 30 DAT, all treatments applied did not significantly influence leaf production as all the plants recorded an average of four (4) leaves each, which increased to eight (8) leaves at the end of 60 DAT. Plants with treatment T12 had an average of Nine (9) leaves, which is significantly higher than those of plants of every other treatment, which all recorded 8 number of leaves (Table 4). Between 90 DAT and 120 DAT, leaves production was significantly influenced by the fertilizer formulations applied to the plant, while the control (T1) and T8 (N:P: K 15:15:15 at 40 Kg Nha^{-1} + AC at 120 Kg Nha^{-1}) recorded the least number of leaves (12 and 13) respectively. Whereas, the highest numbers of leaves within the same period were recorded by plants with T4, T5, and T11, each with an average of 17 leaves, respectively. At 150DAT, leaves production was highest (19) from the plant with T11(N:P: K 15:15:15 at 80 Kg Nha^{-1} + AC at 80 Kg Nha^{-1}), and this was significantly higher than those of T6, T7, T8, and T9 with 15 leaves respectively (Table 4). This result was consistent with that obtained for plant height and plant stem diameter in this study,

which further confirms the report of Cavalcante et al. (2014) that 160 Kg Nha-1 is adequate for coffee production, a finding that can also be extended to Noni production, as shown in this study. At 180 DAT, a few plant defoliation occurrences were observed, which distorted the trend of leaf production as influenced by the treatments applied in the study. This can be attributed to the plant root tips that had started growing beyond the soil depth of the experimental polythene pots at this stage.

Table 4. Effect of organic and inorganic fertilizers on the early growth performance of the Noni plant number of leaves

Treatment	30 DAT	60 DAT	90 DAT	120 DAT	150 DAT	180 DAT
T1	4^{a}	8^{b}	12^{c}	15^{abcd}	18^{abc}	16^{ab}
T2	4^{a}	8^{b}	12^{c}	16^{abcd}	18^{ab}	15^{b}
T3	4^{a}	8^{b}	13^{bc}	16^{abcd}	17^{abc}	18a
T4	4^{a}	8^{b}	12^{c}	17^{a}	18^{a}	17^{ab}
T5	4^{a}	8^{b}	13^{bc}	17^{a}	17^{abc}	18^{ab}
T6	4^{a}	8^{b}	14^{ab}	15^{abcd}	15^{bc}	17^{ab}
T7	4^{a}	8^{b}	13^{bc}	13^{cd}	15^{c}	16^{ab}
T8	4^{a}	8^{b}	13^{abc}	13^{d}	15^{c}	16^{ab}
T9	4^{a}	8^{b}	13^{ab}	14^{bcd}	15^{c}	17^{ab}
T10	4^{a}	8^{b}	14^{abc}	16^{abc}	16^{abc}	17^{ab}
T11	4^{a}	8^{b}	14^{ab}	17^{a}	19^{a}	17^{ab}
T12	4^{a}	9^{a}	14^{a}	16^{ab}	17^{abc}	16^{ab}

Means value within a column followed by the same letter(s) are not significantly different at P = .05

3.5 Plant Dry Matter (G)

The results of dry matter obtained showed that the application of fertilizer had a significant positive influence on plant biomass accumulation. The PDM for leaves, stem, and root (3.593, 2.720, and 4.220 g/plant, respectively) from the control (T1) plant was the least compared to every other treatment in the study. These results were also significantly lower (*P*=.05) compared to PDM of leaves, stem, and root of T12 (7.733, 7.937, and 9.887 g/plant), which were the highest data recorded in this study (Table 5). The gradual release of nutrients from composted organic wastes, especially nitrogen and phosphorus, probably enhanced plant yields later in the study, whereas inorganic fertilizers provided immediate but potentially short-lived benefits. This sustained nutrient availability from compost is consistent with earlier findings (Eghball et al., 2001), suggesting that organic amendments can support long-term plant growth and productivity.

Table 5. Effect of organic and inorganic fertilizers on the early growth performance of Noni plant dry matter (g/plant)

Treatment	LEAVES	ROOT	STEM
T1	3.593^{c}	2.720^{c}	4.220^{d}
T2	5.017^{bc}	4.190^{bc}	5.937^{cd}
T3	5.713^{ab}	5.127^{abc}	6.900^{bc}
T4	5.210^{bc}	5.273^{abc}	7.933^{abc}

T5	7.787[a]	4,880[abc]	7.933[abc]
T6	6.860[ab]	4.437[bc]	7.613[abc]
T7	6.290[ab]	5.127[abc]	6.563[c]
T8	7.280[a]	5.140[abc]	7.313[bc]
T9	6.717[ab]	6.213[ab]	6.923[bc]
T10	6.770[ab]	4.827[abc]	8.120[abc]
T11	7.270[a]	6.197[ab]	9.183[ab]
T12	7.733[a]	7.937[a]	9.887[a]

Means value within a column followed by the same letter(s) are not significantly different at P = .05

4. CONCLUSION AND RECOMMENDATIONS

The use of composted manure in combination with N :P: K 15:15:15 ensured an early and continuous supply of nutrients, resulting in higher growth performance of Noni over a period of six months, as shown in the study. Since the recommended rate of fertilizer application for coffee production is 160 Kg Nha^{-1}, the same is therefore recommended for Noni production provided it is supplied in the combination of organic and inorganic fertilizers as was done with T11 (N:P: K 15:15:15 at 80 Kg Nha^{-1} + AC at 80 Kg Nha^{-1}) which gave the best growth performance in this study except for T12 (N:P: K 15:15:15 at 80 Kg Nha^{-1} + AC at 120 Kg Nha^{-1}) that had higher PDM but not significantly different from T11 which is more economically friendly.

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EFFECT OF DIFFERENT SOURCES OF ORGANIC MANURE ON THE GROWTH RESPONSE of (*Gmelina arborea)* Seedlings

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ABSTRACT

This study investigated the impact of various organic manure sources on the growth of *Gmelina arborea*. It was carried out at Aliko Dangote University of Science and Technology, Wudil. The experiment lasted for 11 weeks. The seed of *Gmelina Arborea obtained from a healthy mother tree located at ADUSTECH's old nursery were planted into polythene pots, thoroughly mixed at a 5:2 ratio with river sand and different types of organic manures (small ruminant, poultry, pig,* and cow dung manures). The experiment was laid out in a Randomized Complete Block Design (RCBD) with five treatments, which were replicated thirty times. Plant height, number of leaves, and germination percentage were assessed weekly. The result obtained from the study shows that the seedlings treated with 5:2 ratio of river sand and small ruminant manure performed best in all the parameters assessed after 11 weeks with 11.73cm for seedlings height, 13per stand for number of leaves, 7.69g for total dry biomass and 23.37g for total fresh biomass produced and this is followed by seedlings treated with cow dung manure which had 11.52cm for seedlings height, 11 per stand for number of leaves, 4.01g as total dry biomass and 14,.21g total fresh biomass produced during the study. It is thus concluded that small ruminant manure is best used as organic manure for raising seedlings of *Gmelina arborea* during its early growth stage in the nursery.

Keywords: *Gmelina arborea*, small ruminant manure, pig, poultry manure, cow-dung, growth rate, biomass, river sand

Background of The Study

Gmelina arborea is widely cultivated in West Africa, primarily for the pulp and paper industries, due to its high productivity and rapid growth, with an eight- to nine-year rotation age (Greaves, 1981; Twimasi, 1991; Yani et al., 2011). *Gmelina arborea* is the most important species for timber production, and several hectares have been planted in different ecological zones (Moya, 2004). *Gmelina arborea* is a deciduous tree of the Verbenaceae family. It is a medium to large tree that reaches about 12-30 m high and 60-100 cm in diameter which is native to tropical moist forest from India, Burma and Sri Lanka to Southern China, Gmelina arborea is widely distributed in Brazil, Gambia, Honduras, Ivory Coast, Malaysia, Malawi, Nigeria, Panama, Philippines and Sierra Leone. It grows best within the temperature range of 18°C to 35°C. It grows well in areas with distinct dry seasons and an annual rainfall range of 1,776 mm to 2,280, with atmospheric humidity of 40% (Oduwaiye, 1996). However, *Gmelina* was originally established in Nigeria for the supply of pulp wood to the country's pulp and paper mills (Akachukwu, 1993). These pulp and paper industries in Nigeria have all closed down, and the species is now used as a building material. These plantations are now a ready source of raw logs for conversion into saw wood of uniform grades and sizes (Adetogun and Omole, 2007). According to Duke (1983),, the wood is one of the best timbers of the tropics, useful for particle board, plywood, corestock, pit props, matches, and saw timber for light construction, furniture, general carpentry, and packaging.

Gmelina arborea is a sunlight-demanding tree, moderately drought resistant, and it has a fairly good fire tolerance. As a result, the rapid increase in demand for Gmelina-based wood products and their other uses, such as raw materials for pulp and paper production, climate amelioration, soil management, and erosion control, has greatly affected the total hectareage of *Gmelina* plantations in Nigeria. **Gmelina** is a source of fodder, food, tannin, and gum, apart from aiding in

nutrient recycling (Etejere et al., 1982; Beet, 1989). Poor management culture of Nigerian forest has led to poor yield and multiplication of timber product given the potentials of the specie, the rate at which the tree species is being felled for forage, commercial and other purposes is on the high side. In contrast, the regeneration and afforestation of the tree species is virtually nothing to write home about as there is an annual decline in the rate of plantation establishment of *Gmelina arborea* in Nigeria. Despite its wide native range, the trees are not very common in natural forests and are mostly found in mixed semi-evergreen or semi-deciduous forests dominated by other species (Ashton and Hall, 2011). To maintain and increase the quantity and quality of production of this species, there is a need to introduce new strategies for its development and establish policies that ensure balanced management and preservation of the tree species to meet its ever-increasing demand. *Gmelina arborea* specie has suffer a neglect in terms of harnessing its full economic potentials for pulp and paper making in our local industries because plantation establishment of the species is still at infant stage in Nigeria, therefore intensive plantation establishment of this tree species will help in boosting the supply of raw material to the concerned industries and also go a long way at salvaging the nation the huge amount of money that might be spent annually on the importation of another exotic species for pulp and paper production.

The substantial increase in demand for timber and timber products has depleted the world's forests (FAO, 2011), including those in Nigeria. Plantation forests have often been considered as a "quick fix" solution to the perennial problems of over-exploitation of the natural forest resources. Plantation forestry in Nigeria started in the early 1900s (Ajayi, 2013). Large-scale plantation forestry in Nigeria was preceded by many successful species and provenance trials, mainly of exotic species. (FAO 2011) reported that the annual planting rate is about 58,000 ha, in which *Gmelina arborea* is one of the trees typically planted in this regard.

For any plantation or reforestation program based on nursery–produced seedlings, such seedlings must be of high quality, exhibiting vigorous growth at the early stage of establishment. The rate of growth of any plant seedling during the nursery is greatly dependent on several cultural practices, amongst which nutrient application remains prominent. Earlier studies have reported the significant influence of soil nutrients on the rate of germination and emergence of plant seedlings. Lack of adequate information on the mode of planting, fertilizer requirement, nutrients, environmental requirements, and nursery techniques, as well as early-stage growth and development behaviors, has seriously undermined attempts to establish large plantations of the species (Ladipo et al., 1994; Rafiqul et al., 2004).

Plantation establishment dependss much on the supply of high-vigour seedlings from nurseries. The production of good and healthy seedlings in the nursery largely depends on many factors, including the fertility of the soil. The production of valuable seedlings in the nursery requires an investment in fertilizer and soil management to improve productivity, as soil fertility is one of the important environmental factors affecting plant growth. Low soil fertility is a major constraint in agriculture and forest productivity (Hausthone, 2005; Tanimu et al., 2007).

To effectively harness the potential of this species, emphasis must be made on improving its demand as a plantation tree. In this regard, the use of organic manure applications becomes essential in forest soil management practice. To regenerate and maintain a forest, the soil must be enriched with essential nutrients. This enrichment could be in the form of fertilizer application, which may be organic or inorganic forms, all of which furnish plants with nutrients necessary for their growth (Offiong et al., 2010). Siddhuraju (2007) reported that during the early stages of growth, trees are very dependent on soil nutrient supply. Failure to manage nursery soil adequately can result in depletion of site quality and a reduction in seedling growth. The dilemma for foresters is how to increase the yield and quality of products for rapidly expanding wood-based industries and for use by a rapidly expanding human population, while simultaneously maintaining environmental diversity. However, it is well understood that the loss of diversity can be minimized in a sustainable manner by increasing the number of species used in production forestry through the cultivation of additional exotic timber species. Given this multipurpose function and utility of Gmelina arborea, it is favored for plantation programs. This study aimed to evaluate the effect of different sources of organic manure applications on Gmelina arborea at the early growth stage to determine the best means of promoting faster seedling growth of the species.

Problem Statement

The natural forests in Nigeria are rapidly diminishing in both size and tree density due to extensive human influences. The alarming rate at which trees are being depleted in the natural forest without adequate replacement calls for urgent attention. *Gmelina arborea* is a highly productive and fast-growing tree species with an eight to nine-year rotation age. However, despite the economic potentials of the species, its sustained provision of timber as the rapid increasing in the use of paper and other benefits is questionable as it is threatened due to the species inability to regenerate under natural condition because of the increasing human pressure, and some environmental factors which hinder the regeneration, Therefore, information on seedlings response to different growth media will provide a better understanding of species requirements which will assist in seedling establishment for regeneration.

Over the years, nursery practitioners have been raising seedlings on conventional potting mixture of ratio 3:1 in river sand + cow dunk manure, therefore there is need to assess the potentiality of the individual manure in question which are cow dung, pig dung, small ruminants and poultry manures with the emphasis of shorting the germination period of the seed in nursery production. It is important due to the increasing use of pulp and paper nationwide, and *Gmelina arborea* is the best tree species for producing paper.

Justification

Considering the socioeconomic aspects of this species, ranging from pulp and paper production, mat making, domestic use as firewood wood and medical uses, hence the need for this study. Although, the use of manure has been found effective for better seed germination and seedling establishment in field crops under controlled conditions, however, no comprehensive study and information have yet been recorded and done to evaluate the response to a wide range of different sources of manure to enhance emergence and growth of Gmelina arborea seed. If positive findings are established in this work, it will help provide a simple, cost-effective, and affordable management strategy for maintaining Gmelina arborea seeds. This research work will investigate the most promising source of manure for maintaining seed germination and seedling attributes of Gmelina arborea seeds, and to ascertain the appropriate or best combinations among the manure types required for the optimum growth of the seedlings under nursery conditions.

Aim and Objectives

The purpose of this study is to compare the effect of different sources of organic manure on the growth response ofG*melina arborea* species.

The specific objectives are:

1) To assess the germination characteristics parameters of Gmelina arborea seed under different sources of manure
2) To assess growth parameters after germination (i.e, leaf production, seedling height)
3) To measure the total dry biomass and fresh biomass of *Gmelina arborea*

Research Questions

1) What is the best source of manure between cow dung, poultry, pig, and small ruminants' manures on the growth response of Gmelina arborea under nursery production?
2) Which source of manure produces the highest weight of total fresh and dry biomass?

Significance of the Study

The significance of the research is:

1) To provide solutions that can assist and simplify educators, the general public, and the government in understanding the growth response of Gmelina arborea to different sources of manure, thereby raising awareness about the best recommended manure.
2) Findings from this research work will also ascertain the extent of different organic manure on the *Gmelina arborea* species.
3) This research work will help to improve the existing literature on the influence of different organic manure on some exotic species, thereby contributing to the body of knowledge.

Research Hypothesis

The research hypothesized that the four sourcess of manure respond differently to the growth of Gmalina arborea seedlings. We therefore aimed to test whether there is a significant difference between the four sources of the manure.

Methodology

Description of the Study Area

Wudil is a Local Government Area in Kano State, Nigeria. Its headquarters are in the town of Wudil on the A237 highway, and along the Kano- Maiduguri road. It has an area of 362 km² and a population of 185,189, as per the 2006 census. The postal code of the area is 713101. Wudil is located between latitudess 11.590N and 11.9220N, and between longitudes 8.750E and 8.973^{0}E. Wudil is 35km from Kano, the climate of Wudil is tropical and belongs to Sudan savannah, the average temperature of Wudil is 26.5°C, and about 755mm of precipitation falls annually (Olofin 2008)

Climatic Conditions of the Study Area

The dry season in Wudil typically begins in November and lasts until March, with daytime temperatures ranging from 30°C to 40°C (86°F to 104°F). The humidity is relatively low during this period, and the weather is generally sunny and dry. The rainy season in Wudil typically starts in April and lasts until October, with rainfalls ranging from moderate to heavy. Temperatures during this period are a bit cooler, ranging from 25°C to 35°C (77°F to 95°F). The humidity is usually high during the rainy season, making the weather feel more humid and sticky.

Materials

The materials used for the study are

Certified seed of g*melina arborea*, river sand, cow dung, pig dung, small ruminants' manure, poultry manure, wheel barrow, shovel, head pan, polythene bags, water, water tank, watering can, rake, hoe, book, pen, meter ruler, electrical weighing balance, seedlings identification tags.

The fruits of *Gmelina arborea* were obtained from a mother tree located at the ADUSTECH old nursery site. The seeds were extracted manually and dried in the air for 1 week under favorable conditions. The seed treatment involved soaking the seeds in water for 24 hours to enhance germination. Cow dung and manure from small ruminants were obtained from the Wudil cattle market. Pig manure was sourced from the Gombe piggery farm, and poultry manure was also obtained from a selected livestock farm in the the Wudil local government area. River sand was also collected from the river Wudil.

Experimental Design and Procedure

Seeds were sown directly into polythene pots with a mixture of river sand and manure (cow dung, poultry, small ruminants, and pig manure), in a ratio of 3:1, and control (river sand). One seed were sown per poly pot, approximately 2cm deep into the pots. The seeds were lightly covered with sand, and watering was done until the seeds germinated. Watering was done twice a day, in the early morning and late evening, to maintain adequate moisture and enhance seed germination. The readings were taken every week.

The treatments are: T1 = 3 head pans of river sand one head pan of cow dung (mixed and 30 polythene sheets was made). T2 = 3 head pans of river sand + 1 head pan of pig manure, (30 polythene bags were made). T3 = 3 head pans of river sand + 1 head pan of small ruminant manure, (30 seeds also were sown). T4 = 3 head pans of river sand + 1 head pan of poultry manure, (30 seeds). T5 = river sand only (which served as a control with 30 seeds sown). A total of 120 seeds were sown for the experiment.

The experiment was arranged in a Randomized Complete Block Design (RCBD) with four treatments and a control, which had six replicates and five rows, making a total of 30 seeds in each plot/block.

However, to achieve objective one, we calculated the germination percentage (GP) for each treatment using the formulae below.

i. GP = Number of germination seeds/Number of seeds sown*100/1
ii. GE = Seeds germination time after sowing.
iii. GD = period from germination emergence to the end of germination.

Objective (2) was achieved by using the formulae below.

i. Seedling height (cm): This was measured using a meter rule graduated in centimeters to determine the height from the soil level to the top of the the terminal bud of the seedlings.
ii. Leaf production: This refers to the total number of leaves present on each seedling, which was determined by counting the leaves.

However, the collected data from objectives (1) and (2) were subjected to an F-test (analysis of variance) to compare the growth response between the four different treatments, which are our selected manures.

The plant fresh weight (g) was determined by carefully and randomly uprooting plants from each treatment after eight weeks. Seedlings were lowered in the bowl of water for easy removal of soil particles attached to the roots and washed off. The plant fresh weight was determined using an electronic weighing scale. Then, they were put into labeled envelopes and oven-dried for 48 hours at 105 °C (Fanda et al., 2022). The samples were allowed to cool down, and then their dry weight was measured using an electronic weighing balance, which was used to achieve objective (3).

Statistical Analysis

All data collected were subjected to analysis of variance (ANOVA) using SAS (9.1) (2000). Significant differences were separated using the Duncan Multiple Range test at a 0.05 probability level.

Result

The result of the germination percentage of *Gmelina*

The results show that there was a significant difference ($p \leq 0.05$) among treatments in seed germination percentage. The mean germination percentage varied from 3.33% to 66.67% (Figure 1). Small ruminant manure exhibited the highest germination percentage (66.67%), followed by control (46.67%), cow dung, and pig dung (26.67%), while poultry manure exhibited the lowest germination percentage (3.33%).

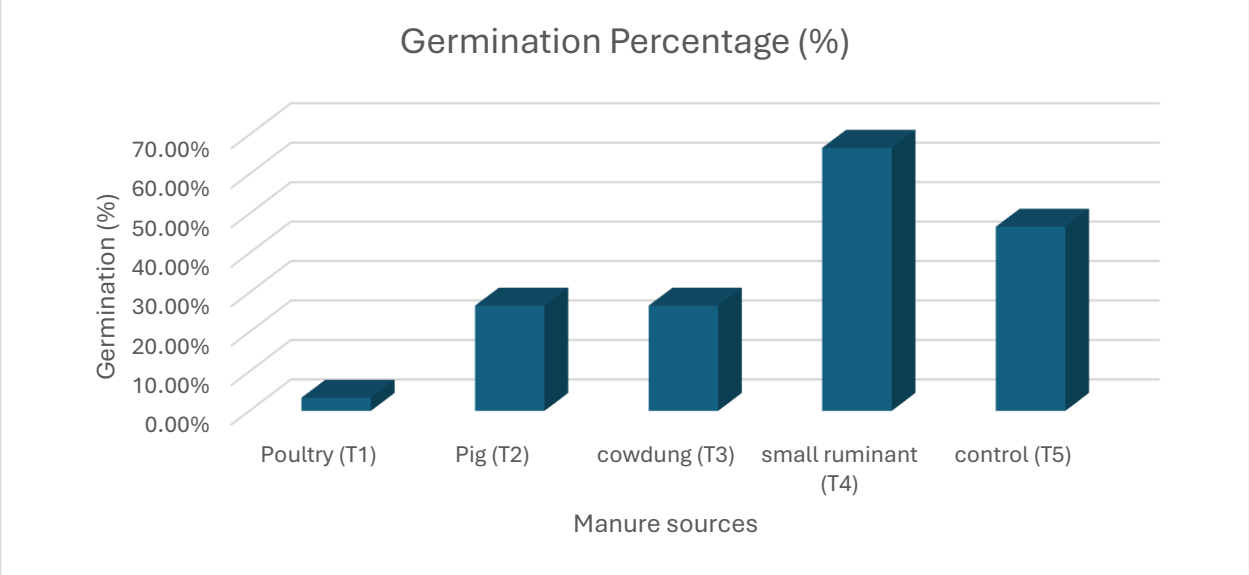
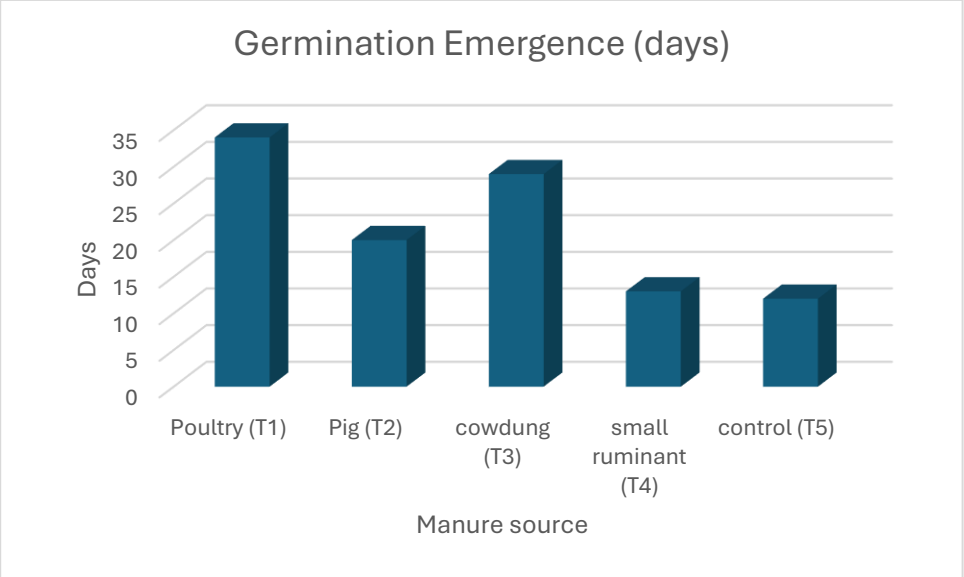


Figure 1. Effect of Different Sources of Manure on the Germination Percentage of *Gmelina arborea.*

Effect of Different Sources of Manure on Germination and Emergence of *Gmelina arborea.*

There was significant variation ($p \leq 0.05$) among treatments in seed emergence. The number of days which seeds of *Gmelina arborea* took to emerge after sowing was earliest in control (12 days) compared to seeds sown in small ruminant's manure treatment (13 days), pig manure treatment (20 days), cow dung treatment (29 days), while poultry manure exhibited lowest germination emergence (34 days) as presented in Figure 2.



Effect of different sources of organic manure on the germination duration of *Gmelina arborea*

There was significant variation ($p \leq 0.05$) among treatments in seed germination duration. Poultry manure exhibited the lowest germination duration (1 day) due to its poor performance, where only one seed germinated from the treatment. This was followed by cow dung manure (14 days), control (23 days), and pig manure (36 days). In contrast, small ruminant manure had the the highest germination duration (43 days). Summary of this result is presented in Figure 3.

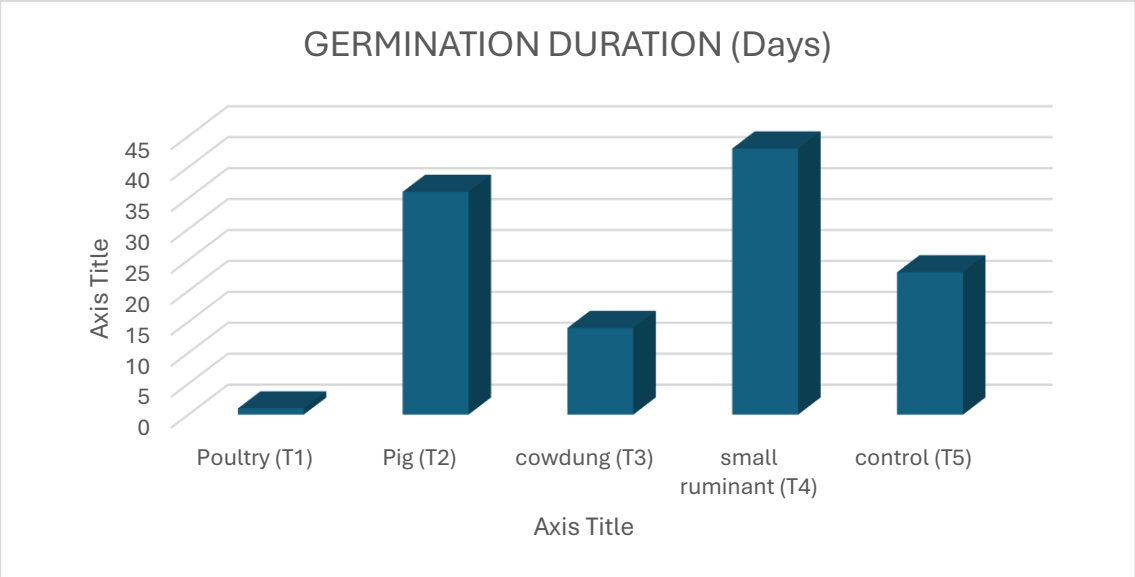


Figure 3. Effect of different sources of organic manure on germination duration of *Gmelina arborea.*

Effect of different sources of manure on the height of seedlings of *Gmelina arborea*

Seedlings of *Gmelina arborea* displayed significant differences ($p \leq 0.05$) in height from 2 to 11 weeks of growth in the nursery. Overall mean seedling height

after 2 to 11 weeks varied. Small ruminant manure treatment seedlings exhibited highest height at 2 to 11 weeks, followed by cow dung treatment despite the lowest performance at 2 to 3 weeks, while control and pig manure treatment seedlings had the average height at week 11 (5.73 and 6.01 cm respectively) and poultry manure treatment had the lowest height mean at week 11 (1.53cm respectively) (Table 1).

Table 1. **Effect of different sources of manure on the height of seedlings of** *Gmelina arborea.*

Treatments.	2wag	3wag	4wag	5wag	6wag	7wag	8wag	9wag	10wag	11wag
T_1 (poultry).	0.00^{b}	0.00^{b}	0.00^{b}	0.07^{c}	0.37^{c}	0.48^{c}	0.00^{c}	0.98^{b}	1.20^{b}	1.53^{c}
T2 (pig).	0.00^{b}	0.04^{b}	0.26^{b}	0.62^{bc}	1.09^{bc}	1.58^{bc}	2.76^{bc}	3.87^{b}	4.79^{b}	6.01^{bc}
T3(cow dung).	0.00^{b}	0.00^{b}	0.03^{b}	0.17^{c}	0.74^{c}	1.55^{bc}	3.06^{bc}	5.21^{b}	6.53^{b}	9.53^{b}
T4 (Small ruminant).	0.06^{ab}	0.34^{ab}	0.67^{b}	1.61^{ab}	2.74^{ab}	4.49^{a}	7.53^{a}	11.18^{a}	14.11^{a}	19.05^{b}
T5 (control).	0.11^{a}	0.69^{a}	1.54^{a}	2.70^{a}	3.26^{a}	3.54^{ab}	4.28^{b}	4.92^{b}	5.28^{b}	5.73^{bc}
SME	**0.04**	**0.14**	**0.27**	**0.45**	**0.66**	**0.85**	**1.18**	**1.66**	**1.99**	**2.54**

Source: Field work 2024, keywords: T1-T5 (treatment 1-5), wag (week after germination)

Effect of different sources of manure on the number of leaves of *Gmelina arborea.*

Significant variations ($p \leq 0.05$) were also observed in the number of leaves among treatments throughout the growth stages. Overall mean leaf number after 2 to 11 weeks ranged from 0.20 at week 2, at week 11 (Table 2). The highest leaf number after 2 to 11 weeks was observed in small ruminant manure treatment. In contrast, the lowest leaf number at week 2 to 4 was observed in poultry manure and cow dung manure treatments (0.00, respectively), and week 6 to 11 in poultry manure treatment not well performed (Table 2).

4.1.5 Table 2. **Effect of different sources of manure on the number of leaves of** *Gmelina arborea.*

Treatments.	**2wag**	**3wag**	**4wag**	**5wag**	**6wag**	**7wag**	**8wag**	**9wag**	**10wag**	**11wag**
T_1 (poultry).	0.00^{a}	0.00^{a}	0.00^{c}	6.00^{a}	0.60^{b}	1.30^{b}	\1.30^{b}	1.77^{b}	1.90^{c}	3.07^{b}
T2 (pig).	0.00^{a}	0.07^{b}	0.30^{bc}	1.00^{c}	1.97^{b}	2.87^{b}	4.40^{b}	5.40^{b}	8.47^{bc}	12.33^{b}
T3 (cow dung).	0.00^{a}	0.00^{b}	0.00^{c}	0.43^{c}	1.73^{b}	3.00^{b}	6.63^{b}	9.33^{b}	12.93^{b}	17.53^{b}
T4 (small ruminant).	0.17^{a}	0.57^{ab}	1.30^{ab}	3.23^{b}	5.77^{a}	9.73^{a}	15.17^{a}	19.83^{a}	27.40^{a}	39.20^{a}
T5 (control).	0.20^{a}	1.13^{a}	2.37^{a}	4.10^{ab}	5.07^{a}	5.77^{ab}	7.20^{b}	8.50^{b}	9.20^{bc}	10.40^{b}
SME	**0.08**	**0.24**	**0.44**	**0.80**	**1.20**	**1.75**	**2.51**	**3.15**	**3.90**	**5.29**

Source: Field work 2024: keywords; T1-T5 (treatment 1-5), wag (week after germination)

Total Fresh and Dry Weight

The total fresh weight was significantly ($p < 0.05$) observed in small ruminant manure. The highest TFW (23.37 g) from small ruminant treatment was slightly different from cow dung (14.21g), but differed significantly ($p < 0.05$) from poultry manure (3.49 g), pig manure (6.98g) and the lowest total fresh weight of (2.61g) from control treatment (Table 3). Also, the total dry weight was observed significantly ($p < 0.05$)

by small ruminant manure with highest mean of (7.69g) followed by cow dung manure treatment (4.01g), pig manure (2.18g) while lowest mean observed in poultry manure (0.82g) and control (0.94g respectively) (Table3).

Table 3. Total fresh and dry biomass

PLANT WEIGHT	TPM	TPG	TCM	TSM	TCL	SME
FRESH BM	3.59^{b}	6.98^{b}	14.21^{ab}	23.37^{a}	2.61^{b}	4.86
DRY BM	0.82^{b}	2.18^{b}	4.01^{ab}	7.69^{a}	0.94^{b}	1.65

Key words; TPM (poultry manure treatment), TPG (pig manure treatment), TCM (cow dung manure treatment), TSM (small ruminant manure), TCL (control treatment), BM (biomass), TFW (total fresh weight)

Discussion

Tree species differed in their manure requirements and preferencess; therefore, effort must be made to evaluate the appropriate fertilizer preferences of each tree species for enhanced growth and development. The genetic characteristics of any plant determine its nutritional uptake and manipulation for growth. This study found that the type and level of organic manure application improved the growth of *Gmelina arborea.* Organic manure consists of the three most important substances for plant growth: nitrogen, Phosphate, and Potash. Manure is added to the soil for several reasons, with the ultimate aim of improving soil nutrients. Various researchers who worked on the effect of organic manures on the growth of some tropical tree species gave similar results to those of the present study (Mbakwe and Nzekwe, 2005; Baiyeri, 2002). The result also agreed with the findings of Mbakwe and Nzekwe (2005), who observed that organic manures had an effect on the growth of Irvingia wombulu (Vermeosen) seedlings; this conformed with the observations obtained in this study. The findings by Baiyeri (2002) on two tropical tree species [Anacardium occidentalis Linn (cashew) and Treculia Africana Decne (African breadfruit)] grown on five nursery media formulated from topsoil and organic manure at different ratios showed a significant effect on seedling emergence of cashew. This study also supported the findings of Orwa et al. (2009), which showed that organic manure improved the growth of *Khaya senegalensis.* Furthermore, organic manure maintains the level of humus in the soil, provides optimal conditions for soil organisms, and replenishes the plant nutrients that have been removed by crops. It finding aligns with the results of Gideon (2012), who reported that organic manure improved soil nutrients, thereby enhancing the seedling growth of Khaya grandifolia.

Manure from small ruminants was found to be effective in improving their early growth. Ndukwe et al. (2011) and Aba et al. (2011) maintained that animal manure is a valuable source of crop nutrients and organic matter, which can improve the soil's biophysical conditions, making it more productive and sustainable for plant growth. Chukwuka and Omotayo (2009) specifically noted that application of organic fertilizers significantly improves the soil chemical properties and nutrient uptake in plants, thereby enhancing plant growth. It confirms the findings of Imoro *et al.* (2012).

In this study, germination emergence, plant height, number of leaves, total fresh and dry biomass were observed to be significantly affected affected by small ruminant manure treatment. The SRM had the highest emergence rate, main daily emergence, and number of emerged seedlings, indicating that it germinated more than the other selected manures. Poultry manure was found to be inactive in the growth and yield of Gmelina arborea, which is contrary to the findings of Owolabi et al. (2013) and Agbo-Adediran and Oso (2014), who reported increased seedling growth with poultry droppings, cow dung, or a combination of both manures. It indicates that seedlings of *G. arborea do not require large quantities of poultry manure in the*

potting mixture, probably due to its high content of essential nutrients (Mukhtar, 2020b). The data shown in this finding suggest that a small quantity of poultry manure is needed to enhance the growth of Gmelina arborea seedlings, and a higher quantity of cow dung is required for the the same. Poultry manure is known to mineralise faster than cow dung in nursery media (Adubasim et al., 2018),

Summary

The study concludes that small ruminant animal manure is a valuable source of fertilizer for the growth of Gmelina arborea, as it has an influence on the growth performance compared to poultry, pig, and cow dung, as well as controls. However, the cow dung performed better than pig, poultry, and control, which means it can be used in the absence of small ruminant manure. Furthermore, small ruminant manure proved to be more superior because it produced better growth attributes, such as plant height, number of leaves, total plant fresh and dry matter (biomass), followed by cow dung. The results obtained in this study therefore suggest that the use of these animal manures should be encouraged to provide leaves and other useful plant parts for pulp and paper use and other purposes, as well as to enhance the quantity and possibility of shortened time for plant maturity. The study shows that a 5:2 mixture of river sand and small ruminant manure proved to be an effective nursery potting mixture and also a a good source of manure for the growth and yield of *Gmelina arborea* tree species.

Recommendation

Based on the results obtained, it is therefore recommended that:

i. River sand and small ruminant manure of 5:2 should be adopted for the growing of *Gmelina* arborea, because it shows the best growth performance for all the parameters measured in the experiment

ii. Cow dung manure should be adopted for growing *Gmelina arborea* in the absence of small ruminant manure.

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Limitations of the Research

The issue of pestss and direct sunlight is one of the most important limiting factors that resulted in altering the data collected every week from the research area. Excessive concentration of rainfall on the seeds during the rainy season can also lead to the immortality of the seedlings. Therefore, measures were taken to address the limitation observed during the research work.

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DETERMINATION OF ABOVEGROUND BIOMASS AND CARBON STOCK OF INDIGENOUS TREE SPECIES IN FALGORE GAME RESERVE, KANO, NIGERIA

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ABSTRACT

Carbon sequestration mitigates global warming and climate change; the amount of carbon stored in vegetation is directly related to its biomass density. Falgore Game Reserve is facing numerous natural and human-induced causes of degradation attributed to illegal exploitation. There is inadequate research tailored towards carbon sequestration in the Falgore National Park. Fifteen temporary sample plots, each 20 x 20 m (400 m²), were established with a 3.7 km interval using a systematic sampling technique. Tree species in each of the temporary sample plots were identified. The height and diameter at breast height (dbh) were measured using a Haga altimeter and Vernier caliper, respectively. The data collected has been analysed in Excel software. The Importance Value Index was used to determine dominant indigenous tree species in the reserve. At the same time, AGB was estimated using an improved allometric equation of Chave et al. (2014), and carbon stock was estimated using a typical carbon fraction of 50% of AGB. The results of the research revealed that Anogeissus leocarpus (Marke) was the dominant indigenous tree species in the reserve, with IVI of 57.42%. The total AGB recorded was (28,732.38 kg) in the entire sample plots, which translates to (14,366.19 kg) of stored carbon, which is equivalent to (23.94 t/ha). Anogeissus leucarpus (Marke) contributed the highest carbon stock, storing approximately 61.66 kg. Despite these findings, the relatively low carbon values observed are due to ongoing illegal exploitation of forest resources. Nonetheless, the reserve plays a crucial role in mitigating climate change through carbon sequestration.

Keywords: Carbon stock, Falgore, Aboveground biomass, Importance Value Index (IVI)

INTRODUCTION

Carbon sequestration via trees and general green spaces is an economical approach to mitigating global warming and climate change. Carbon dioxide is one of the most prevalent greenhouse gases, significantly contributing to global warming. It is the major causal factor for global warming (Lal, 2008). Billions of tons of Carbon dioxide are locked as organic matter around the planet, but due to natural processes, the organic matter is converted into fuels such as diesel, coal, peat, wood, and petrol (Pareta and Pareta, 2011). When fuel is burned, carbon dioxide is released into the atmosphere, increasing atmospheric carbon concentrations and contributing to climate change and global warming. In other words, high rates of industrialization, human population growth, urbanization, and deforestation have contributed to increased CO2 in the atmosphere (Orji, 2014). However, trees absorb carbon through the process of photosynthesis and store it in their leaves, litter, branches, stems, roots, and soil in varying proportions, giving rise to different components of carbon pools within a forest ecosystem (Luckai et *al*. 2002). Therefore, forest ecosystems play a crucial role in mitigating climate change. Assessment of carbon dioxide sequestered by a tree gives us an estimate of the quantity of carbon emitted into the atmosphere when a particular tree is deforested or degraded.

Furthermore, it helps quantify carbon stocks, which in turn may enable us to understand the current status of carbon stocks and also derive near-future changes in carbon stocks (Vashum and Jayakumar, 2012). According to the Intergovernmental Panel on Climate Change (IPCC, 2021), forests store approximately 80% of the total terrestrial above-ground carbon and over 70% of soil organic carbon.

Indigenous tree species are those that have evolved naturally within a specific region, adapting to local conditions over the course of centuries. These species often exhibit characteristics that make them efficient for long-term carbon storage, such as slower decomposition rates, extensive root systems, and high wood density (Thompson *et al*., 2011).

MATERIALS AND METHODS

This research was carried out at Falgore Game Reserve, Kano State. The FGR, formerly known as Kogin Kano Game Reserve, is located between longitudes 8° 30’ and 8° 50’ East and latitudes 10° 46’ and 11° 20’ North, 150 km south of Kano city (Fig.1).

It has an estimated area of 92,000 hectares and borders the Tiga artificial lake to the north and the Lame Burra Game Reserve in Bauchi State to the southeast. Falgore Game Reserve also borders three Local Government Areas (Doguwa, Sumaila, and Tudun Wada)

In a normal year, the mean annual rainfall in FGR is estimated at 1000 mm, decreasing northwards to approximately 800 mm around Kano Metropolitan. The FGR is a gallery forest with a high density of tree species and high floristic density found within the open Northern Guinea Savannah woodland vegetation type, though with elements of the Sudan Savannah in the northern tip.

The area is characterized by rocks of the basement complex, dating back to the Precambrian age, to the west and south, and the Chad Formation to the northeast. The first two geomorphological types are part of the high plains of Hausa land, while the third is of the Chad plains (Olofin 2000). According to the 2006 census figures from the National Population Commission of Nigeria, Kano State has a population of 9,383,682 people, making it the most populous state in the country. The annual population growth rate of the state is 3%, and therefore, it is projected to be 12,198,786 by 2016 (FRN 2010). More than half of the area's inhabitants are farmers who grow cereals, legumes, and vegetables. In addition to cultivation, livestock rearing and trade are major activities in the state (KNARDA, 2006). The major inhabitants of the state are the Hausa and Fulani ethnic groups, whose main sources of livelihood are livestock rearing, farming, hunting, and fishing. Although hunting and fishing as livelihood activities cause little or no harm to the forest ecosystem when carried out conventionally, they can have adverse effects if not managed properly.

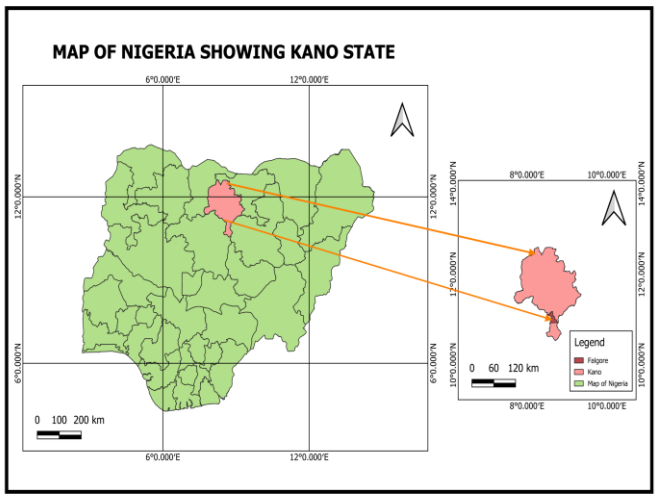
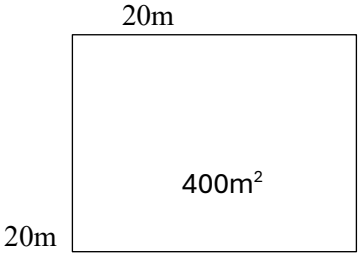


Figure 1: Map of the Study Area (Source: GIS LAB, CDA, BUK)

Sampling Techniques

Fifteen temporary sample plots of 20 x 20 m (400m^2) each with a 3.7km interval were established using systematic sampling.



Data Collection

Tree species in each temporary sample plot were identified and counted. The height and diameter at breast height (dbh) were measured using a Haga altimeter and a Vernier caliper, respectively. The data collected has been enumerated using mathematical computations in Excel software.

Data Analysis

IVI Computation:

IVI was used to identify the dominant indigenous tree species in the study area using the formula as adopted by Ammonium et *al*. (2019): IVI = RD + RDo + RF

Eq. 1

Where:

- RD is the Relative Density expressed as, RD(%)= $\left[\frac{ni}{N}\right]\times 100$

Where ni = number of individual species; N= Total number of species in the entire community (Husch *et al*., 2003).

- RF is Relative Frequency expressed as: number of plots where the specie occurred/Total number of plot occurrences for all species×100
- While RDo is the Relative Dominance, which is computed using: RDo = $\frac{(Bai)}{\sum Ban} \times 100$

Where Bai = Basal area of individual tree belonging to species *i,* Ba_n stand basal area of all species as adopted by (Onyekwelu *et al.,* 2007)

Estimation of Aboveground Biomass and Carbon Stock:

The above-ground biomass of the indigenous trees was determined using the Chave *et al*. (2014) estimation equation, which is a widely used formula for AGB of tropical forests, and the equation is as follows:

$AGB=0.0673*(\rho D^2H)^{0.976}$

Eq 2

Where:

- AGB = Above ground biomass in kg/tons
- ρ = wood density in g/cm^3
- D = Diameter at breast height in cm
- H = Heights in meters

The wood density of most species was obtained from the West African wood density database by Carson *et al*., (2012), and the wood density value used for the rest of the species (*Bauhinia rufescence, Boswellia dalzielli, Comretum collinum, combretum molle, Cossopterix ferifuga, Lannea acida)* was 0.7g/ cm^3 as adopted by Hyong *et al*. (2024).

The Carbon stored was derived by multiplying the aboveground biomass by 50%, which is the typical carbon fraction adopted by Dongs et al. (2024).

RESULTS AND DISCUSSION

A total of 195 individual tree stands representing 26 species from 15 temporary sample plots were identified in the study area.

Importance Value Index Analysis

Table 1 shows the species Density (n) and the sum of the Basal area, which were computed to determine the Relative Density (RD), Relative dominance (RDo), and Relative frequency (RF), used for the computation of the the importance value index (IVI). Based on the species Density analysis presented in Table 1, the tree species with highest density(n) in descending order include, *Combretum molle* (44), *Anogeissus leocarpus* (42), *Balenite aegyptiaca* (19), *Crossoptix ferifuga* (13) with *Terminalia macroptera* (11) and *Diterium microcarpum* (11). In contrast, species with lowest representation include: *Combretum ghalense* (1*), Combretum collinum* (1), *Zizziphus macronata* (1), *Bombax costatum* (1), *Jakaranda* (1), *Prososfis africana* (1), *strychno spynosa* (1), and *Ptericarpus erinaceaus* (1).

Anogeissus leocarpus (Marke*)* has occupied the highest Basal area (10.49m^2) despite having less frequency than *Combretum molle,* which occupied (6.74m^2). The species with the least Basal area is *combretum ghalenese* with (0.02m^2 a basal area.

Based on the Importance Value index analysis presented in Table 1 and Figure 2, the ecologically dominant tree species in Falgore Game Reserve in descending order are: *Anogeissus leocarpus* (57.42%), *Combretum molle* (53.48%), *Balanite aegyptiaca* (23.26%), *Terminalia macroptera* (19.46%), *Diterium macrocarpum* (18.55%), and *Vitellaria paradoxa* (18.50%). Others include *Crossopterix ferifuga* (18.36%), *Tamarindus indica* (14.78%), *Diospyrous mespiliformis* (8.18%), *Burkea Africana* (7.68%), and *Acacia seyal* (6.83%), which together account for

about 82.17% of total species dominance. At the same time, *Combretum ghalense* has the lowest value of (1.83%). It confirmed the finding by Mama and Adeniyi (2005), which identified the dominant tree species in the savannah as *Anogeissus leocarpus*, *Burkea Africana*, and *Vitellaria paradoxa*.

Table 1: Importance Value Index Table

Tree Species	Density (n)	Frequency (f)	BA(m2)	RD(%)	RF (%)	RDo(%)	IVI(%)
Acacia nilotica	2	2	0.03	1.03	2.53	0.06	3.62
Acacia seyal	5	2	0.74	2.56	2.53	1.73	6.83
Anogeissus leocarpus	42	9	10.49	21.54	11.39	24.49	57.42
Balenite aegyptiaca	19	6	2.54	9.74	7.59	5.93	23.26
Bauhinia rufescence	2	1	0.07	1.03	1.27	0.16	2.45
Bombax costatum	1	1	0.73	0.51	1.27	1.69	3.47
Boswellia dalzielli	2	2	1.19	1.03	2.53	2.78	6.34
Burkea Africana	4	3	0.79	2.05	3.8	1.83	7.68
Combretum collinum	1	1	0.08	0.51	1.27	0.18	1.96
Combretum ghasalense	1	1	0.02	0.51	1.27	0.05	1.83
Combretum molle	44	12	6.74	22.56	15.19	15.72	53.48
Crossopterix ferifuga	13	4	2.84	6.67	5.06	6.63	18.36
D. mespiliformis	6	3	0.56	3.08	3.8	1.31	8.18
Diterium microcarpum	11	6	2.28	5.64	7.59	5.31	18.55
Jakaranda	1	1	0.15	0.51	1.27	0.36	2.14
Lannea acida	2	2	0.94	1.03	2.53	2.18	5.74
Parkia biglobosa	1	1	1.71	0.51	1.27	4	5.78
Piliostigma reticulatum	4	2	0.19	2.05	2.53	0.44	5.02
Prosofis Africana	1	1	0.65	0.51	1.27	1.52	3.3
Pterocarpus erinaceus	1	1	0.71	0.51	1.27	1.65	3.43
Strychno spynosa	1	1	0.03	0.51	1.27	0.06	1.84
Tamarindus indica	7	4	2.62	3.59	5.06	6.12	14.78
Terminalia macroptera	11	5	3.21	5.64	6.33	7.49	19.46
Vitellaria paradoxa	8	5	3.46	4.1	6.33	8.07	18.5
Zizziphus macronata	1	1	0.03	0.51	1.27	0.08	1.86

Zizziphus mauritiana	4	2	0.06	2.05	2.53	0.14	4.72
Grand Total	**195**	**79**	**42.84**	**100**	**100**	**100**	**300**

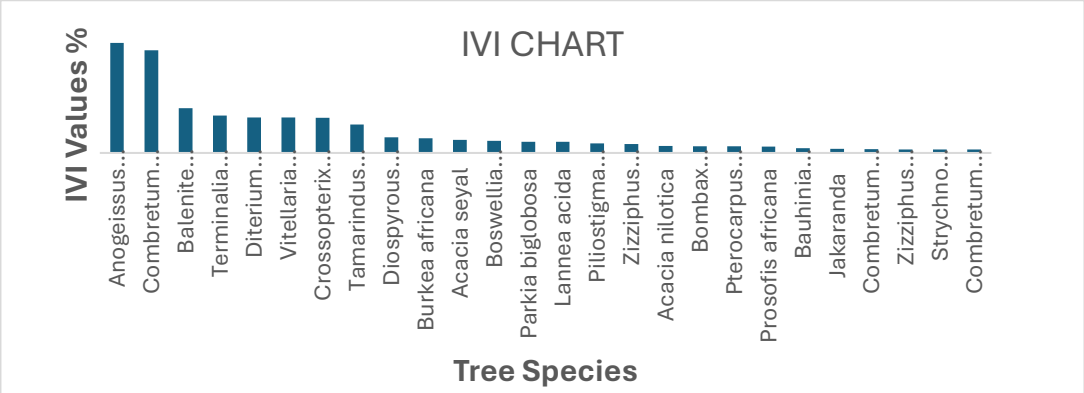


Figure 2: Importance Value Index Chart

Aboveground Biomass and Carbon Estimation in the Reserve

A total of 26 species were discovered in Falgore Game Reserve, and from Table 2 below, it can be noticed that *Anogeissus leocarpus* had the highest AGB value of 12,333.19 kg. It was due to its exceptional overall height and Diameter at Breast Height (dbh), as well as its status as the dominant tree species in the reserve. While *Combretum ghalenese* records the lowest AGB Value of (8.35kg). This study revealed that the Study area stored an overall AGB of 28,732.38 kg.

The highest aboveground carbon is also stored *by Anogeissus leocarpus* (6,166.59 kg/m²), followed by Combretum molle (1,582.36 kg). This study finds that the total above-ground carbon stored in the reserve amounts to 14366.19 kg.

The AGB value in this study is lower than the value (40.5 t/ha) reported by Innocent et al. (2014) for the mangrove ecosystem of the Rufiji River Delta, Rufiji District, Tanzania. It's also lower than the value reported by Ibrahim et al. (2020) in the Majiya Fuelwood Reserve, Sokoto State, Nigeria. The amount of carbon sequestered in this reserve is also lower than the amount of carbon recorded in Eda SNR (48978.2kg), Nigeria, and (53608.40kg) in Katarania-Ghat Wildlife sanctuary, India, as reported by Adekunle *et al*. (2014)

The above-ground biomass of tropical forests plays a vital role in the global carbon cycle. It provides essential data needed for the extrapolation of biomass stocks in an ecosystem (Wittman et al., 2008). According to (Ramachandran *et al*., 2007), the forest ecosystem is one of the major practical ways of reducing large concentrations of atmospheric carbon that result in global warming. However, the amount of total AGB of (28, 732.38 kg) and the above ground carbon of (14366.19 kg) which is equivalent to 23,943.65 kg/ha (23.94 t/ha) estimated in this research reveals the contribution of the reserve in cleaning the atmospheric CO_2 dirt, thus supports the above claim by Ramachandran.

The AGB and above-ground carbon recorded in this study were affected by anthropogenic activities taking place in the reserve, thereby reducing the rate of carbon sequestration and storage.

Table 2: Aboveground Biomass and Carbon

Tree Species	Mean DBH(cm)	Mean Height(m)	WD(g/cm3)	AGB (kg)	C.S

Acacia nilotica	4.2	7.2	0.65	10	5
Acacia seyal	12.88	6.58	0.73	216.47	108.23
Anogeissus leocarpus	15.74	15.11	0.91	12333.19	6166.59
Balenite aegyptiaca	11.54	4.06	0.73	709.44	354.72
Bauhinia rufescence	6.45	4.6	0.7	16.38	8.19
Bombax costatum	30.4	13.2	0.4	267.84	133.92
Boswellia dalzielli	27.4	9.6	0.7	560.33	280.17
Burkea Africana	15.4	7.13	0.73	309.86	154.93
Combretum collinum	10	4.8	0.7	19.67	9.83
Combretum ghasalense	5.3	7.1	0.7	8.35	4.17
Combretum molle	12.23	6.68	0.7	3164.73	1582.36
Crossopterix ferifuga	15.39	8.55	0.7	1184.6	592.3
D. mespiliformis	9.9	5.52	0.81	172.73	86.37
Diterium microcarpum	15.87	9.09	0.73	1230.44	615.22
Jakaranda	14	6.9	0.46	35.88	17.94
Lannea acida	24.4	9.25	0.7	425.06	212.53
Parkia biglobosa	46.7	22.9	0.58	1523.44	761.72
Piliostigma reticulatum	7.68	3.35	0.58	28.78	14.39
Prosofis Africana	28.8	13.5	0.91	549.51	274.76
Pterocarpus erinaceus	30	8.9	0.56	246.71	123.36
Strychno spynosa	5.8	6.6	0.73	9.65	4.83
Tamarindus indica	20.23	8.93	0.81	1685.6	842.8
Terminalia macroptera	18.5	9.75	0.81	2033.35	1016.68
Vitellaria paradoxa	22.19	9.78	0.7	1957.95	978.98
Zizziphus macronata	6.5	6.5	0.7	11.4	5.7
Zizziphus mauritiana	4.3	6.7	0.7	21.01	10.51
Grand Total	**14.62**	**8.98**	**0.76**	**28,732.38**	**14,366.19**

Indigenous Tree Species that Store the Highest Aboveground Carbon

According to Ramachandra *et al.* (2007), the forest ecosystem is one of the major practical ways of reducing the large concentrations of atmospheric carbon that results in global warming.

From Table 6 above and Figure 4 below, showing 26 species representing 195 individual trees enumerated

from the reserve, it shows that *Anogeissus leocarpus* sequesters the highest amount of aboveground carbon (6166.59 kg), followed by *Combretum molle* (1582.36 kg), *Terminalia macroptera* (1016.68 kg), *Vitellaria paradoxa* (978.98 kg), and *Tamarindus indica* (842.80 kg), which amounts to 74% of the total aboveground carbon stored in the reserve.

This research is in agreement with Adekunle *et al.* (2014), who found that Anogeissus leocarpus recorded the highest values in terms of biomass, carbon stock, and CO2 removal, despite being the most exploited species in the tropical rainforest ecosystem of South West Nigeria.

According to Adekunle *et al.* (2014), the discrepancies in the amount of carbon values observed in research could be linked to several factors, such as methods of biomass calculation, Sampling intensity, inter-location variations, and climatic conditions. Moreover, the age of the reserve or individual trees, species composition, and the management techniques adopted could be among the factors.

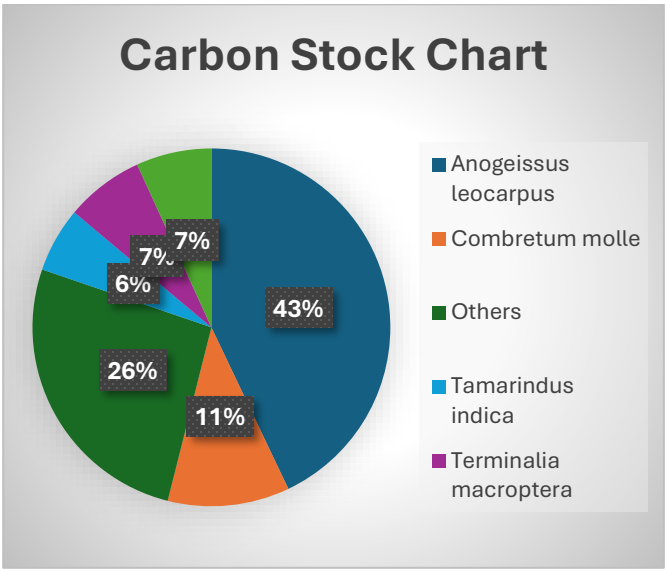


Figure 3: Carbon Stock Chart

CONCLUSION AND RECOMMENDATION

This study assesses the carbon sequestration capacity of indigenous tree species in Falgore Game Reserve, Kano State, Nigeria. A total of 195 individual tree stands representing 26 different species were measured based on heights and diameter at breast height (DBH). These parameters were used in mathematical computations to determine the dominant indigenous tree species in the reserve using Importance Value Index (IVI) equations, the above-ground biomass, the above ground carbon sequestered by the indigenous tree species in the reserve, and the indigenous tree species that sequestered the highest amount of above-ground carbon.

The findings of this study reveal that *Anogiessus leocarpus* is the dominant indigenous tree species in the reserve. The reserve stored a total of 28,732.38 kg and 14,366.19 kg of above-ground biomass and above-ground carbon, respectively. *Anogiessus leocarpus* also recorded the highest amount of carbon sequestered among the indigenous species in the reserve.

These findings highlight the ecological significance of the reserve, *Anogiessus leocarpus*, and underscore the need to preserve the reserve so it can continue playing its role in mitigating the effects of global warming and climate change.

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ASSESSMENT OF GERMINATION AND GROWTH PERFORMANCE OF AFRICAN MESQUITE (*Prosopis africana*) SEEDLINGS USING ORGANIC MEDIUM

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ABSTRACT

The research was conducted at the nursery site to assess the germination rate and growth parameters (height and collar diameter) of the study seedlings of the Prosopis africana species. Organic medium(Cow dung and poultry waste) to stimulating farmers' interest in the planting, utilization, establishment, as well as enlightening and encouraging them towards its domestication to arrest the steady disappearance of this multipurpose forest fruit species. Viable seeds were collected from the mother tree and pre-soaked in hot water, thoroughly washed with clean water before being planted in a mixture medium of a a 2:1 ratio in each treatment. Polythene pots of 2x3cm dimensions were used. A Complete Randomized Design (CRD) was arranged in three replications of the experiment. The results show that in germination, the percentage differs significantly, with cow dung recording a higher germination rate of 59.22%, followed by the control at 47.03%. Poultry waste was the least at 33.03% respectively. Whereas in collar diameter,, the results also indicated that cow dung had the highest value of 3.5mm, followed by poultry waste at 2.4mm.At the height of the study, the results showed that poultry waste recorded the highest value of 69.66%, followed by cow dung with 51.9%, and pure river sand recorded the least value of 43.4%, respectively. The overall findingss for collar diameter, height, and germination rate were recorded as significantly different ($p < 0.05$) in the experiment assessed. This study has demonstrated that poultry waste and cow dung have a highly significant effect on improving germination and enhancing seedling emergence.

Keywords: *P. africana*, seedlings, Cow dung, Poultry waste, germination, and growth performance.

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INTRODUCTION

Most forest fruit trees have difficulty with germination, hence their propagation is adversely affected by seed coat dormancy, resulting in poor imbibition and germination potential. Various authors have employed different methods to break or reduce dormancy and improve germination rates in different forest seeds, including cold water, hot water, acid treatment, and the use of different organic media. These treatments and organic media aimed at making the seed coat permeable, either naturally or artificially, thereby enhancing germination and growth performance (Agbogidi et al., 2007).

Prosopis Africana enriches the soil by fixing nitrogen; its leaves are rich in protein, and the sugar pods are used as foodstuffs for feeding ruminants in Nigeria. The pulp of the pods contains 9.6% protein, 3% fat, and 53% carbohydrates, providing an an energy value. In some areas, its fermented seeds are used as a condiment in Nigeria, as *Parkia biglobosa,* the *Prosopis africana* seeds are fermented and used as condiments. The *P. africana* seeds are used in Nigeria and Benin in the preparation of a local condiment. Similarly, *P. africana* is used in the preparation of foods such as soups and baked products, as well as in the manufacture of sausages and cakes (Ajiboye et al., 2014).

Decomposition is one of the most important processes that accounts for carbon and nutrient recycling in crop land and forest systems (Shi, 2013). It is controlled by factors such as the carbon to nitrogen ratio (Richard &Trautmann, 2014), pH, and nutrient balance in the medium, particle size, temperature, moisture content, and porosity (Fredrick *et al,* 2017). Livestock manure (cow dung and poultry waste) has a low carbon-to-nitrogen ratio of 25–30, which is ideal for providing the required energy for microbial activity, as well as a high water-holding capacity. The high concentration of macronutrients in cow dung provides the initial nutrients required for the decomposition process. These factors make cow dung an ideal component for mixing with river sand to enhance its decomposition and meet both immediate and long-term plant nutrient requirements.

Cow dung has been extensively used in crop production and is often recommended as a soil nutrient replenishment strategy in low-income countries (Okalebo *et al*., 2006). Forest soils are commonly used to raise seedlings in the nursery. The soils are collected from natural forests. The soils may not contain all essential nutrients, either due to leaching or utilization by undergrowth. The addition of small quantities of inorganic fertilizer is recommended as a supplement for the good growth of seedlings in the nursery. Seedlings' height is one of the growth parameters used to determine the planting stage of seedlings in the field. However, height is not a satisfactory measure for grading plants, and the recommended root collar diameter is highly correlated with the survival of seedlings in the field. (Fredrick *et al,* 2017).

There is minimal knowledge on how cow dung and poultry dropping can be utilized as a growth medium for establishing forest seedlings, as well as the appropriate mixing ratios for enhanced decomposition. Thus, this study aimed to mix poultry droppings with cow dung and/or forest soil to form a nutrient-rich growth medium that can be used to raise high-quality, fast-growing tree seedlings. Specifically, the study sought to find out how the growth media comprising poultry droppings, forest soil, and/or cow dung affect the growth characteristics of African mesquite (*Prosopis africana*) seedlings raised in the forest nursery Station of HAFED Poly Kazaure.

Most forest trees have difficulty with germination; hence, their propagation is adversely affected by seed coat dormancy, resulting in poor imbibition and reduced germination potential. Various authors have employed different methods of breaking or reducing dormancy and improving germination rate in different forest seeds, including cold water Adejomo, 2005; Oni *et al*., 2005; Owonubi *et al*., 2005; Dachung and

Verinumbe, 2006; Isikhuemen and Kalu, 2006). These treatments, according to Umar (2005), aim to make the seed coat permeable either naturally or artificially, thereby enhancing germination.

MATERIALS AND METHODS

The Study Area

The research was carried out at the Department of Forestry Technology nursery site, School of Agriculture, Hussaini Adamu Federal Polytechnic, Kazaure. Kazaure is an emirate and a local government area situated in Jigawa State of northwestern Nigeria (between latitudes 12 41 28.7" - 13 00' N and longitudes 007 50' E - 008 25' 21.1"E). It falls within the Sudan Savannah zone, covering a total area of 690 sq mi (1,780 km²). It also has a total population of 161,494 (Note: Kazaure LGA only) according to the 2006 Census. The temperature ranges from 15.85 °C to 390 °C and falls as low as 10 °C during the Hamatan season. Rainfall ranges from 500mm in the north to 1,200mm in the south. The people of the area are predominantly farmers who engage in both rainy and dry season farming (irrigation) (Abdullahi *et al.,* 2016).

SAMPLE COLLECTION/PROCEDURES

The fruits of *Prosopis africana* were collected from the mother tree at the School of Agriculture, Hussaini Adamu Federal Polytechnic, Kazaure. The fruits collected were manually depulped to expose the seeds, which were used for the study. Polythene pots with dimensions of 2x3cm were used and filled with a River sand mixture containing medium (cow dung and poultry waste) in replications.

The seed treatments involved pouring the seeds into cool water for viability or confirmation tests. The viable seeds were also removed, which were soaked in hot water for 24 hours in a container for a germination test. Afterward, the seeds were planted in the nursery from each polythene pot mixture.

RESULTS AND INTERPRETATION

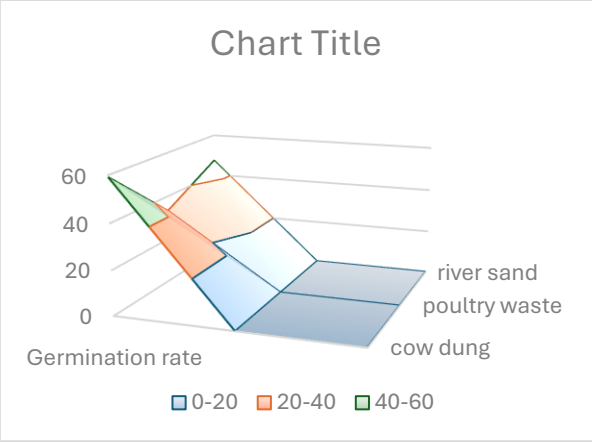
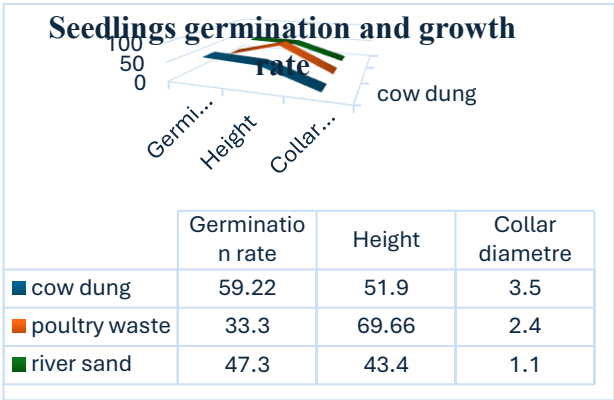


Figure I: The germination and growth performance of the study species seedlings



	Germination rate	Height	Collar diametre
cow dung	59.22	51.9	3.5
poultry waste	33.3	69.66	2.4
river sand	47.3	43.4	1.1

Figure II Germination rate of the study species seedlings

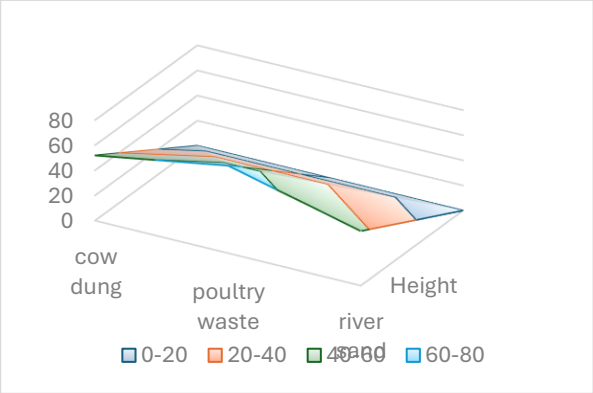


Figure III: The height of the study species seedlings

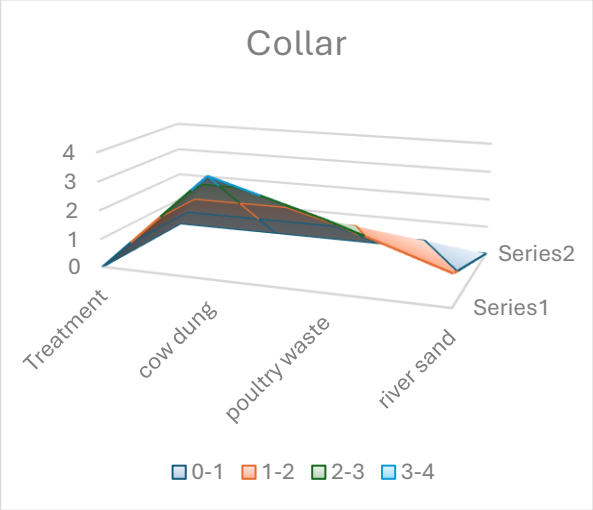


Figure IV: The Collar diameter of the study species seedlings

Table 1: One-Way Anova of height parameter from the mixture medium

SOURCE OF VARIATION	SS	DF	MS	F	P-VALUE	F-CRIT
Between groups	81.61968	2	40.80984	1.265132	0.317283	3.885294
Within group	387.0885	12	32.25737			
Total	4687082	14				

The statistical table above, based on the results, shows the growth performance of the height parameter from different mixtures of medium, indicating significant differences ($p > 0.05$) compared to the

results obtained in the P-value from the experiment.

Table 2: Shows the one-way ANOVA statistical table of collar diameter from the mixture medium

SOURCE OF VARIATION	**SS**	**DF**	**MS**	**F**	**P-VALUE**	**F-CRIT**
Between groups	0.577333	2	0.288667	1.179837	0.340581	3.885294
Within group	2.936	12	0.244667			
Total	3.513333	14				

The statistical table above indicates that the growth performance in collar diameter of different mixtures of the medium showed significant differences ($p > 0.05$) from the final results obtained in the experiment.

A SAMPLE PLATE OF THE GERMINATED SEEDLINGS OF DIFFERENT MIXTURES OF MEDIUM

Plate I: The germinated seedlings of poultry waste mixture media

Plate II: The germinated seedlings of the Cow dung mixture media

Plate III: The germinated seedlings of the control media (River Sand)

DISCUSSION

Tree species are of great value to many rural communities in developing countries, due to their economic and environmental benefits, which include the provision of timber, shade, shelter, medicine, and fuelwood. However, the forestry program faces a serious problem in Nigeria, as the high cost of tree seedlings, which have been attributed to the long time spent in the nursery, is due to poor-quality of soil. Organic and inorganic fertilizers are added to increase soil nutrients for the proper germination and growth of different tree species. The study was carried out to examine the effect of organic manure on the germination and early growth of Prosopis africana seedlings. Of which the findings indicated that the germination rate in Cow dung was recorded at the highest of 59.22%, followed by river sand (Control) at 47.03%, and the least recorded treatment was poultry waste at 33.03%. The result shows significance different of ($p > 0.05$). This finding is similar to prior reports of Ugese *et al*, (2007) and Fredrick *et al,* (2017) that cow dung mixtured medium of the seeds have the heighest potential in germination rate and thickness of the seedlings emergence, and was similar to the previous research by (Finch 2006) on Seeds dormancy and the control of germination. New Phytologist germination of *Ziziphus mauritiana* fruit. It is also similar to that of (Vasquez *et al.* 2017), who discovered a low germination rate on *Bursera glabrifolia* and *Bursera bipinata* using inorganic substances.

In morphological terms, in terms of height and collar diameter, the study juveniles' Poultry waste (TR2) recorded the highest parameters at 69. 66cm followed by Cow dung (TR1) 51.9cm, and the least was control with 43.4cm, respectively. Its indicated that there were significant differences ($p < 0.05$) in the treatments. The research also is similar to the finding of (Hoque *et al* 2004) who reported a similar result in morphological characteristic of *Michelia champaca* seedlings after applying of NPK fertilizer, and was also per away to same research by (Fredrick and Wamalwa (2017); on leaves of *Psidium guajava* in Addition of small quantities of inorganic fertilizers recommended as a supplement for good growth in the nursery.

The collar diameter of the species juveniles was reported to have the highest percentages in Cow dung (TR1), which recorded about 5.4mm, followed by poultry waste (TR2) with 2.2mm, and TR3 recorded the least with 1.1mm. The research also revealed that there is significant differences ($p>0.05$) between treatment 1 and 2, and the finding closer to that of (Zeng *et al* 2013) on Root collar diameter growth of eucalyptus seedlings which determined under different fertilization treatments, that higher fertilization of seedlings result in higher growth and steam growth also similar to that of (Houghton 2008. Additionally, it is closer to that of Abdullahi et al. (2014), who researched different Amaranthus species using organic and inorganic fertilizers.

CONCLUSION

Many researchers have used different fertilizerss and their modifications to predict the morphological status of various tree species seedlings. This research has proven that the use of inorganic media helped improve the production of many tree spices within the study location, and the result is promising enough to warrant further

research, which could lead to controlling the menace of their extinction.

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Theme: *Forest Sustainability in the face of climate change and insecurity: Innovative technologies and Strategies*

RELATIONSHIP BETWEEN TREE SLENDERNESS COEFFICIENT AND GROWTH CHARACTERISTICS OF TREE SPECIES IN KANO ZOO'S BOTANICAL GARDEN

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Abstract

This study investigated the relationship between the tree slenderness coefficient (TSC) and tree growth characteristics in Kano Zoo's Botanical Garden. We measured diameter at breast height (DBH), tree height, and other variables in 20 temporary sample plots. Pearson correlation and linear regression analysis were used to establish relationships and develop predictive models. Results showed TSC was negatively correlated with DBH, basal area (BA), and volume (for 6 out of 10 species), but positively correlated with tree height (for 6 out of 10 species). All trees fell under the low slenderness category, indicating wind resistance throw. The Shannon-Weiner diversity index revealed moderate species diversity. Multiple linear regression models that included additional tree variables (DBH, BA, and tree height) had better fit statistics than base models. A multiple linear regression model is recommended for estimating TSC from DBH, BA, and tree height. The findings suggest that tree species in the study area are resistant to wind throw, and the developed model can be used for predicting TSC. This study offers valuable insights into the growth characteristics and slenderness of trees in the Kano Zoo's Botanical Garden, thereby contributing to sustainable forest management practices.

Keywords: Tree height, Tree slenderness coefficient (TSC), Basal Area (BA), Diameter at breast height (DBH)

INTRODUCTION

The tree slenderness coefficient is defined as the ratio of total height (H) to the diameter at breast height (DBH) when both H and DBH are measured in the same units. The coefficient is related to tree taper and is the inverse of the DBH/H ratio, which is often used to ensure uniform taper over the entire main stem of the tree (Wang *et al.* 1998). In silvicultural studies, the tree slenderness coefficient often serves as an index of tree stability, or resistance to windthrow (Navratil, 1995). The likelihood of a tree being blown over by the wind may be influenced by several factors that interact with each other. These factors include tree attributes (e.g., tree height, taper/form, the size and shape of the crown, and the size and shape of the root system), site conditions (e.g., soil characteristics), and local wind characteristics (e.g., average wind speed, frequency of wind gusts). The most promising approaches for determining tree and stand stability to wind throw are those that integrate tree stability characteristics (e.g., slenderness coefficient) with local stand (e.g., average tree height), site, topography, and windiness features (Navratil *et al.* 1994).

However, besides basic structural variables such as basal area, tree slenderness is also a measure recognized as a good indicator of wind throw stability in trees. Proper and adequate silvicultural treatments at the early stage of plant development have the ability to influence tree form and other physiological characteristics (Shamaki 2022). It indicates the shape of trees and, together with tree vitality, provides insight into the general stability of planted forests (Dodan and Perić, 2019).

The usefulness of the tree slenderness coefficient as an index of tree resistance to wind throw is of great importance because the stability of trees in botanical gardens or many other urban spaces could be determined from the ratio of the tree height to diameter. However, various studies focus mainly on plantations, leaving urban spaces and botanical

gardens largely unexplored. Knowledge of the relationship between tree and stand slenderness coefficient will help botanical garden management understand the structure and stability status of their stands. Kano Zoo's Botanical Garden serves as a hotspot for biodiversity conservation in northwestern Nigeria. As such, this study aimed to develop a Tree Slenderness Coefficient (TSC) indices model for biodiversity conservation in Kano Zoo's Botanical Garden, which could also serve as a baseline means of assessing the stability of trees to wind throw in many other urban spaces in Nigeria.

Materials and methods

The study area

The Kano Zoological Garden and Wildlife Management Agency in Kano, Nigeria, features a botanical garden that showcases a variety of plant species. The botanical garden is a serene and educational space that offers visitors the opportunity to learn about the diverse flora of the region. It is located at a latitude: 12.0159° N and a Longitude: 8.5167° E, as shown in Figure 1 below.

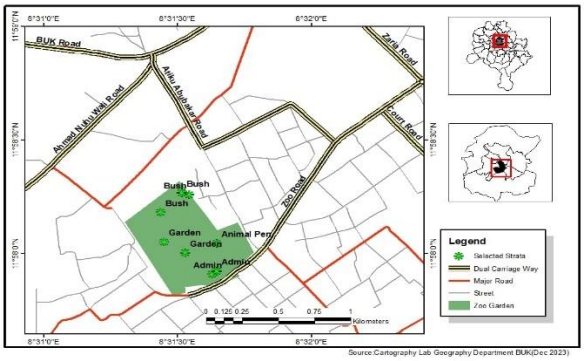

Figure 3.1: Location Map of Kano Zoological and Botanical Garden
Source: Cartography Lab Geography Department BUK, 2023

Data Collection

Data was collected from temporary sampling plots established within the Kano Zoo botanical garden. A 20 m by 20 m plot was delineated using a a measuring tape, with a ranging pole used to demarcate its boundaries. Twenty random plots were selected, resulting in the identification of 20 tree species as adopted from Shamaki (2022). Tree height and diameter were taken. Height measurements were obtained using a Hagga altimeter, while diameter at breast height was measured using a measuring tape. Diameter measurements at the middle and top were obtained using a Spiegel relaskop. Readings were taken at a horizontal distance of 20 meters, with a scale of 20 utilized for both the Hagga altimeter and Spiegel relaskop.

Subsequently, tree volume, basal area, and tree slenderness coefficient were computed using the following procedures:

- Volume estimation. The volume of individual trees was measured using Newton's equation developed for tree volume estimation (Husch *et al.* 2003):

$$V = h\pi\left(\frac{D_b^2 + 4D_m^2 + D_t^2}{24}\right)$$

Where:

V = Tree volume (m^3), H = Tree height (m), D_b = Diameter at base (cm), D_m = Diameter at middle (cm) and D_t = Diameter at top (cm)

Basal Area (BA)

$$BA = \frac{\pi D^2}{4}$$

Where: BA = Basal Area (m^2) , D = Tree diameter (cm)

Slenderness coefficient (TSC)

$$TSC = \frac{THT}{DBH}$$ Where: TSC = Tree slenderness coefficient , THT = Total tree height (m) and DBH = Diameter at breast height (m)

Tree species diversity was assessed using the Shannon diversity index to examine the occurrence of species in the study area, utilizing the following formula:

$$H' = -\sum_{i=1}^{s} pi \ln(pi)$$

Where: H' is the Shannon Diversity Index, S is the total number of species in the community, and pi is the proportion of individuals belonging to the iith species.

Correlation Analysis

Correlation analysis was undertaken to evaluate the strength and direction of the relationship between tree slenderness coefficients and various tree

growth characteristics, encompassing diameter at breast height, tree volume, basal area, and tree height, which were either measured or computed from the collected data. Species occurring at least three times were exclusively considered for correlation and subsequent analysis, as correlation analysis necessitates a minimum of two instances of the same species for reliable interpretation.

Model Development

A two-stage modelling approach was adopted in developing models for predicting TSC from other tree characteristics. In the first stage, simple linear regression models relating TSC to DBH and TSC to BA was developed. In the second stage, a multiple linear regression model that incorporates tree height into the base model, which relates TSC to DBH, was used. This model was then expanded to relate TSC to BA, improving the predictive ability.

The entire field data was split into estimation (70%) and validation (30%) sets. A multiple linear regression procedure in SPSS version 23.0 was used to fit both base models and models that incorporate tree height and Diameter at Breast Height (DBH). Model validation statistics (R^2, SEE, P-value) were generated during the model development process. For effective model validation of the developed models, each model was used to predict the slenderness coefficient using the measured DBH values in the validation dataset. The estimated TSC values from the developed models was then compared with the actual TSC computed using the goodness-of-fit test.

RESULT AND DISCUSSION

The results in Table 1a and 1b show the descriptive statistics obtained from the dataset, indicating its suitability for the study, as evidenced by the low standard deviation across all variables, suggesting minimal variability within the dataset.

Table 4.1a: Summary Statistics Showing TSC, DBH, H, BA, and Volume

Species	Statistic	Freq	TSC	DBH (cm)	H (m)	BA (m^2)	Vol (m^3)
Acacia senegal		**9**					
	Mean		39.2	38.3	14.3	0.1253	1.7633
	Min		10.9	24.2	9.0	0.0460	0.3907
	Max		61.4	64.2	19.2	0.3056	5.4354
	SD		10.9	12.2	3.4	0.0838	1.7007
Azadrachta indica		**13**					
	Mean		36.4	29.6	10.0	0.0782	1.0239
	Min		22.3	13.4	6.5	0.014	0.1441
	Max		63.6	58.2	14.0	0.2664	4.3001
	SD		9.7	11.5	1.9	0.0655	1.0730
Delbergia sissoo		**20**					
	Mean		58.6	22.8	12.1	0.0479	0.7166
	Min		30.7	10.2	7.7	0.0082	0.1453
	Max		107.1	41.4	18.0	0.1344	2.8864

	SD	19.7	9.8	3.1	0.0418	0.7779
Delonix regia	**9**					
	Mean	24.6	39.6	9.6	0.1273	1.4946
	Min	18.2	29.3	6.5	0.0673	0.4564
	Max	50.9	13.0	37.6	0.2036	3.5351
	SD	5.6	7.6	2.0	0.0494	1.0326
Ficus benghalensis	**4**					
	Mean	30.9	38.7	11.6	0.1257	1.2600
	Min	23.6	27.7	9.2	0.0602	0.6062
	Max	33.8	55.1	13.0	0.2384	2.1701
	SD	4.9	11.8	1.8	0.0786	0.7507

Table 4.1b: Summary Statistics Showing TSC, DBH, H, BA, and Volume

Species	Statistic	Freq.	TSC	DBH (cm)	H (m)	BA (m^2)	Vol. (m^3)
Gmelina arborea		**6**					
	Mean		56.0	27.4	14.4	0.0630	1.0408
	Min		44.8	15.9	12.2	0.0199	0.8418
	Max		79.8	36.0	16.5	0.1016	1.5492
	SD		15.0	7.9	1.8	0.0333	0.2563
Khaya senegalensis		**14**					
	Mean		39.6	43.6	15.8	0.1834	3.1065
	Min		23.0	16.2	6.5	0.0207	0.2104
	Max		61.4	98.7	26.0	0.7645	15.0743
	SD		11.9	21.6	5.2	0.1921	3.7933
Mangifera indica		**3**					
	Mean		24.2	59.2	14.3	0.2804	3.4432
	Min		23.2	51.2	13.0	0.2062	2.2685
	Max		25.4	70.3	17.0	0.3886	5.0608
	SD		1.1	9.9	2.3	0.0958	1.4479
Tamarindus indica		**3**					

	Mean		25.7	40.6	10.3	0.1310	1.8814
	Min		21.5	37.2	10.0	0.1089	1.7773
	Max		28.2	46.5	10.5	0.1696	2.0385
	SD		3.7	5.1	0.3	0.0335	0.1384
Terminalia mantaly		**10**					
	Mean		35.8	38.5	13.6	0.1228	1.8340
	Min		28.5	20.7	7.7	0.0336	0.2335
	Max		47.6	50.0	17.5	0.1961	5.2060
	SD		5.6	9.5	3.1	0.0554	1.6031

Table 4.2: Species Diversity

Species	**Frequency**	**Pi**	**LnPi**	**Pi*LnPi**
Acacia nilotica	2	0.020	-3.932	-0.077
Acacia albida	2	0.020	-3.932	-0.077
Acacia Senegal	9	0.088	-2.428	-0.214
Adansonia digitata	1	0.010	-4.625	-0.045
Albizzia lebbek	2	0.020	-3.932	-0.077
Azadrachta indica	13	0.127	-2.060	-0.263
Delbergia sissoo	20	0.196	-1.629	-0.319
Delonix regia	9	0.088	-2.428	-0.214
Faidherbia albida	1	0.010	-4.625	-0.045
Ficus benghalensis	4	0.039	-3.239	-0.127
Gmelina arborea	6	0.059	-2.833	-0.167
Khaya senegalensis	14	0.137	-1.986	-0.273
Mangifera indica	3	0.029	-3.526	-0.104
Piliostigma thonningii	2	0.020	-3.932	-0.077
Syssidium guinensis	1	0.010	-4.625	-0.045
Tamarindus indica	3	0.029	-3.526	-0.104
Terminalia mantaly	10	0.098	-2.322	-0.228
Total	**102**	**1**		**-2.456**
Shannon species Index		**H**		**2.456**

The table 4.2 presents data on species diversity in a given area, including the frequency of occurrence for each species, the relative abundance (Pi), the natural logarithm of the relative abundance (LnPi), and the product of Pi and LnPi. The Shannon species diversity index (H) is also provided.

Table 4.3: Correlation Coefficients between TSC and Tree Variables

Species	DBH (cm)	H(m)	BA(m^2)	Volume(m^3)
Acacia Senegal	-0.592	0.324	-0.571	-0.423
Azadrachta indica	-0.775	-0.471	-0.678	-0.570
Delbergia sissoo	-0.690	0.118	-0.655	-0.549
Delonix regia	-0.452	0.524	-0.408	0.121
Ficus Benghalensis	-0.909	-0.488	-0.941	-0.768
Gmelina arborea	-0.894	-0.323	-0.856	-0.529
Khaya senegalensis	-0.641	0.006	-0.599	-0.502
Mangifera indica	-0.302	-0.064	-0.272	0.190
Tamarindus indica	-1.000	0.995	-1.000	0.240
Terminalia mantaly	-0.417	0.196	-0.427	-0.254

Table 4.3 presents the correlation coefficients between the tree slenderness coefficient (TSC) and various tree variables, such as diameter at breast height (DBH), height (H), basal area (BA), and volume, for different tree species.

Table 4.4: Showing the Classification of the Tree Species into Different Slenderness Categories

Tree species	Mean TSC	Category
Acacia senegal	39.2	*0-69*
Azadrachta indica	36.4	*0-69*
Delbergia sissoo	58.6	*0-69*
Delonix regia	24.6	*0-69*
Ficus beneghalensis	30.9	*0-69*
Gmelina arborea	56.0	*0-69*
Khaya senegalensis	39.6	*0-69*
Mangifera indica	24.2	*0-69*
Tamarindus indica	25.7	*0-69*
Terminalia mantaly	35.8	*0-69*

Table 4.4 classifies different tree species into different slenderness categories based on their mean Tree Slenderness Coefficient (TSC).

Table 4.5: Generalized Simple Linear Regression Model for All the Species

Model	Parameter		SEE	R^2	P values
	a	b			
SC=a+b DBH	63.66	-0.676	13.003	0.41	0.000*
SC= a +b BA	48.55	-74.116	14.484	0.27	0.000*

SEE = standard error of the estimate, BA = Basal area, SC = slenderness coefficient

*= significance, a = intercept, b is the slope coefficient.

Table 4.6: Generalize Multiple Linear Regression for All the Species

Model	Parameter			SEE	R^2	P values
	a	b_1	b_2			
SC = a + b_1 DBH + b_2 H	39.90	-1.051	2.995	8.44	0.75	0.000*
SC = a + b_1 DBH + b_2BA	83.95	-1.770	155.57	11.88	0.51	0.000*

SEE = standard error of the estimate, BA = Basal area, SC = slenderness coefficient

*= significance, a = intercept, b1 and b2 =slope coefficients for the DBH and Height (H).

The model fitting procedure was a two-stage method that produced two sets of models for predicting TSC. The first set, termed as base models, predicted TSC from DBH, and TSC from Basal area. While the second set uses both DBH and Height, Basal area and DBH in predicting the TSC (Tables 4.5 and 4.6)

Discussion

Based on the descriptive statistics resultss, the data set appears quite suitable for the intended study, as the standard deviation for all variables is relatively low, indicating low variability in the data set. The mean TSC for all species considered in the botanical garden is approximately 58.6, indicating low variability in the dataset. Table 1a and 1b also capture minimum, maximum, and mean values. The mean DBH values for all the species considered range from 22.8 to 59.2, total height ranges from 9.6 to 15.8, Basal area ranges from 0.0207 m^2 to 0.1344 m^2, and volume ranges from 0.7166 m^3 to 3.4432 m^3. These three variables were consistent with the normal trend recorded by (Oladoye *et al.* 2020; Shamaki and Oyelade, 2022; and Ige, 2017) in their various studies.

The Shannon species diversity index (H) for Kano Zoo's Botanical Garden is 2.456. This value represents a measure of the overall species diversity considered in the study, taking into account both the number of species (richness) and their relative abundances (evenness).

A Shannon diversity index value between 1.5 and 3.5 is considered to represent moderate species diversity, while values above 3.5 are considered high diversity, and values below 1.5 are considered low diversity (McDonald, 2003; Magurran, 2004). The observed value of 2.456 in the study area falls within the range of moderate species diversity.

The Negative correlation between TSC and DBH in Table 3 suggests that tree size, rather than height, predominantly influences the slenderness coefficient in the botanical garden. Larger trees tend to be more stable, and taller trees tend to be more susceptible to wind throw. Similarly, the consistently higher correlation between the tree slenderness coefficient (TSC) and diameter at breast height, compared to other tree characteristics, suggests that DBH is a more reliable predictor of slenderness coefficient than other variables. Shamaki (2022) also

recorded a similar pattern of relationship among the major tree species grown in northwestern Nigeria, where he reported a negative correlation value for all three species he worked on. Wang *et al.* (1998) also reported a negative correlation value for all five species he worked on in the boreal mixed forest.

The tree slenderness coefficient value decreases with increasing average size for the 10 species considered in the study area. However, the decrease in TSC value is more pronounced for *Mangifera indica, Tamarindus indica, and Delonix regia* than for the other tree species considered in the study. The low slenderness coefficient value recorded for *Mangifera indica, Tamarindus indica*, and *Delonix regia* is a result of the presence of numerous tree forks, which can be attributed to poor silvicultural practices in the study area, resulting in reduced stem size. Oladoye *et al*. (2020) reported a similar pattern of decreasing TSC values with increasing tree size or tree species in the Omo Biosphere Reserve, with other tree characteristics (crown length, volume, and height) showing low correlation with the the tree slenderness coefficient. Adeyemi and Adesoye (2016) also reported similar results while working on some tree species in a tropical rainforest of Nigeria. Onilude and Adesoye (2007) and Ezenwenyi and Chukwu (2017) reported similar results in their various studies, as found in this study.

The table categorizes different tree species based on their mean Tree Slenderness Coefficient (TSC) into their slenderness category. The result from the slenderness coefficient classification showed that all the tree species in the study area fall under the low slenderness coefficient category, which implies that the trees have low susceptibility to damage caused by wind. This result is consistent with the findings of Smudl (2004) and Novak (2006); Kontogianni *et al.* (2011) who reported in their studies that forest trees with a slenderness coefficient below 80 indicate excellent stability. Trees with a low slenderness coefficient are less susceptible to breakage than those with a high slenderness coefficient, which this study agrees with the findings of Eguakun and Oyebade (2015).

A lower slenderness coefficient indicates that the trees have larger crowns, a lower centre of gravity, and a better-developed root systems. The desirable height-to-diameter at breast height (DBH) ratios for adequate wind resistance vary according to species and region (Ige, 2017). In general, trees with a higher slenderness coefficient are more susceptible to wind throw than trees with a lower slenderness coefficient (Shamaki and Oyelade, 2022). Since low slenderness coefficient is usually indicating a higher resistance to wind throw, the relationships confirmed suggest that silvicultural treatments, such as producing long crowned trees, and maintaining appropriate stand density throw spacing, thinning or gradually harvesting of overstory, can help reduce the risk of wind throw (Wang et al 1998; Eguakun and Oyebade 2015). As noted by Liu *et al.* (2003) and Shamaki and Oyebade (2022),

Based on the fit statistics of the base model, the simple linear regression model that includes DBH and BA all show significant predictive coefficients but low coefficients of determination for all the species considered for the study. From the estimated R^2 value 27 to 41% of the total variation in observed tree slenderness coefficient values was explained by the fitted base model even though the statistics produced from the validation data set using the candidate model produce some indication of accuracy of prediction but the low R2 value percent as a determinant of a better fit necessity the need for using an additional tree variable to improve the predictive capacity of the model.

The multiple linear regression was further assessed by estimating the TSC using the validation dataset and the result of the validation shows better estimate of the TSC with low standard error of the estimate to improve the performance of the selected base model, another independent variable (height) was included to form a new model for all the species. When the height variable was included in the model (DBH and H), there was a remarkable improvement in the fit statistics, producing a strong R2 value and low SEE for all the species. The R^2 rises from 41 to 0.75 for (DBH and H) and from 0.27 to 0.51 (BA and DBH) in tables 4.4 and 4.5, respectively.

This improvement was recorded by using additional tree variables, indicating that using DBH alone or BA alone for predicting TSC may not produce the best model, but adding an additional variable (H) does. This finding is consistent with the study conducted by Shamaki (2022), Shamaki and Oyelade (2022), and Oladoye *et al.* (2022) in their various research

CONCLUSION

Based on the findings of this study, it can be concluded that tree size is a strong determinant variable for tree stability, as the tree slenderness coefficient values decrease with increasing tree size or diameter. Even though tree DBH is a good predictor of TSC, predicting the tree slenderness coefficient value using DBH and additional tree variables could improve the accuracy of the prediction. A multiple linear regression model was found to be the best for predicting the Tree slenderness coefficient value from DBH, BA, and Height of the tree species considered in the study. Since tree slenderness coefficient values have been widely used for determining tree stability in many parts of the world, its application can be extended to botanical garden and other recreation or relaxation spaces in Kano, Nigeria to guide management and policy makers in choosing the most likely wind resistant species in botanical gardens and other recreational areas for the safety of the people.

Recommendations

Based on the findings, the following recommendations are made:

1. Researchers should consider species-specific variations and environmental factors when comparing the relationships between the slenderness coefficient and tree growth characteristics relationships
2. People involved in the management of botanical gardens should be educated on silvicultural practices or tending operations they can carry out to produce tree species that are not forked or susceptible to wind throw.
3. It is important to continue monitoring and assessing tree slenderness relationships in diverse ecological contexts to improve our understanding of these complex relationships.
4. Based on the findings, Mangifera indica and Delonix regia exhibited the lowest slenderness coefficient values, making them highly recommended species for future planting within the botanical garden."
5.

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Eucalyptus camaldulensis AQUEOUS EXTRACT ALLELOPATHY ON *Arachis hypogaea*: A COMPARATIVE STUDY

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Abstract

A nursery experiment was conducted to investigate the allelopathic effects of *Eucalyptus camaldulensis* on growth variables (seedling height, girth, and number of leaves) of *Arachis hypogaea* (groundnut). Aqueous leaf extracts of *Eucalyptus camaldulensis* (cold and hot water solutions) were used at different rates (0%, 25%, 50% and 100%) as treatment to determine their effects on groundnut. The aqueous extract was formed by dissolving leaf powder of dried *Eucalyptus camaldulensis* (0g, 25g, 50g, and 100g) in 1 liter of cold water, and another was boiled for a the hot water extract. The study employed a Randomized Complete Block Design (RCBD) with 70 polythene bags and 10 replicates per treatment level. The results showed significant inhibition of seedling growth, with the hot treatment (T2, 25 %) exhibiting the highest inhibitory effect in the seedling height (12.120 %), and (T2, 25 %) in the hot treatment showing the highest inhibitory effect in the seedling girth (1.070 %), also hot treatments (T2, 25 % and T4, 100 %) showed the highest inhibitory effect with 36.800 number of leaves in both. The hot *Eucalyptus camaldulensis* aqueous extract had a greater inhibitory effect on the growth rate compared to the cold aqueous extract; the results showed significant variation ($P < 0.05\%$). The study concluded that *Eucalyptus camaldulensis* allelopathy can have a negative impact on groundnut production. Therefore, it is recommended that *Arachis hypogaea* should not be planted in association with *Eucalyptus camaldulensis* trees due to its inhibitory effects (allelopathy) on plant growth.

Keywords: *Eucalyptus camaldulensis*, Alllelopathy, *Arachis hypogaea*

INTRODUCTION

Plants can influence each other's growth and development through allelopathy, a process where they release chemicals that impact nearby species (Gupta et al., 2007). These allelochemicals can be dispersed through various means, including decomposition, root secretions, and volatile emissions, ultimately hindering the germination and growth of surrounding plants. Various plant parts, such as leaves, roots, bark, and flowers, can contain these bioactive compounds (Kato-Noguchi, 2021). The phenomenon (Allelopathy) has both beneficial and harmful effects. Negatively it causes auto toxicity, soil sickness, and hinders or inhibits the growth and germination of receptor plants. Positively it helps in the control of pests and diseases in plants (Bachheti et al., 2020).

Furthermore, the negative impact of allelopathic trees on adjacent crops, resulting from the release of allelochemicals into the environment through leaching by dews or rain, litter decomposition, roots exudation or direct volatilization, has become a pressing concern in recent times, particularly with the growing recognition of forestry as a separate discipline (Oyun, 2006).

The issue of allelopathy, which inhibits the growth of plants or agricultural crops, is alarming (Chu et al., 2014). Often, poor harvest performance is attributed to the soil or seed quality, but another significant factor is allelopathy. It can lead to a decrease in biodiversity (Chu et al., 2014). Unaware of this, farmers may intentionally or unintentionally plant harmful tree species, such as *Eucalyptus camaldulensis*, which contains allelochemicals that negatively impact nearby crops. As a result, these trees can harm agricultural productivity and biodiversity.

Similar studies have found that the inhibitory effects of *Eucalyptus camaldulensis* depend on the concentration level of the extract, with litter fall

exhibiting higher effects at higher concentrations of materials and vice versa (Ahmed et al., 2008). Now, *Eucalyptus camaldulensis,* being the target tree of this research, is widely distributed in the study area, and the effect of the allelochemicals present in the tree is very high, but the rate of the effects is unknown. So the rate of these effects is investigated. This research aims to investigate the allelopathic effects of *Eucalyptus camaldulensis* on the growth rate of *Arachis hypogaea* while the specific objectives of the study are; to investigate the rate of the inhibitory effects of aqueous extracts of *Eucalyptus camaldulensis* on groundnut at different level of concentrations, to compare the effects of cold and hot *Eucalyptus camaldulensis* aqueous extracts on the growth performance of *Arachis hypogaea*.

MATERIALS AND METHODS

Description of the study area

The experiment was conducted at Aliko Dangote University of Science and Technology, Wudil. The geographical location of the site is situated between latitudes 110 ° 48' 18'' N and 51 ° 40 '0'' longitude, and approximately 37.5 m above sea level. The study area has bare vegetation present. The annual rainfall ranges from 850 to 870 mm, while the minimum and maximum temperatures range between 26 and 33 °C. The relative humidity of the region is consistently low, ranging from 40 to 51.3% (Olofin et al., 2008).

Experimental procedures

The leaves were dried under a shed and then ground into a powder. Three different amounts of the powdered leaves (25g, 50g, and 100g) were dissolved in 1000ml (1 liter) of water, respectively. The extract was prepared in two ways. In the first method,, the extract was heated at a mild temperature, and in the second method, the leaf powder was soaked in cold water for two days. After preparation, the results were filtered using a cotton cloth, and the extract was stored for further use.

The experiment was conducted at the Department of Forestry and Wildlife Management nursery. In each phase, 70 polythene bags were used, with 30 bags allocated to each treatment (cold water and hot water) and 10 bags serving as controls (0%). Within each treatment (cold and hot), 10 bags were assigned to each concentration level as replication (25%, 50%, and 100%).

The polythene bags were filled with a mixture of soil and organic manure (cow dung) in a 3:1 ratio. The mixture was watered for seven days to allow it to stabilize. Seeds were planted at the same time and depth (5-7 cm). Treatments were applied starting the next day, and readings were taken accordingly from May 2023 to August 2023.

Experimental design and treatment

The experiment was conducted using a Randomized Complete Block Design (RCBD), with two treatment factors (cold water and boiled water) and four concentration levels (treatments) of *Eucalyptus camaldulensis* aqueous solution (0%, 25%, 50%, and 100%). This design allowed for the evaluation of the effects of both treatment factors and concentration levels on the experimental outcomes.

Data collection

The growth rate was assessed by measuring seedling height (cm), girth (cm), and number of leaves for four (4) weeks, from week two to five.

Statistical analysis

The analysis of variance (ANOVA) was employed to determine the variability among the treatments. Statistical Analysis System (SAS) software (version 9) was used for the statistical analysis. Means were compared using Least Significant Difference (LSD) at 5% significance level.

RESULTS AND DISCUSSION

Comparison of seedling height (Hot and Cold treatments)

Table 1 below presents the seedling height values of *Arachis hypogaea* in a nursery experiment, recorded for four weeks, treated with a hot water mixture of aqueous extract of *E. camaldulensis*. The results reveal a statistically significant difference ($P < 0.05$). In (WAS 2, 3,4 and 5) the highest plant height was observed in T1 (control) (5.44cm, 10.80cm, 16.32cm and 21.76cm) respectively, followed by T3 (4.12cm, 8.20cm, 12.34cmand 16.42cm), then T4 (3.75cm, 7.48cm, 11.10cm and 15.00cm) and the lowest height value was observed at T2 (3.03cm, 6.06cm, 8.99cm

and 12.76cm) respectively. The findings are in line with the research of Wasihun (2013), which showed that E. camaldulensis has an inhibitory effect on the shoot length of some arable crops compared to the control. While Table 2 below presents the nursery experiment using cold Eucalyptus aqueous solutions, the results reveal a significant difference ($P < 0.05$) between the treatments. In (WAS 2, 3,4 and 5) the highest plant height was recorded in T1 (control) (5.44cm, 10.88cm, 16.32cm and 21.76cm) respectively, followed by T2 (3.97cm, 7.94cm, 11.91cm and 15.43cm), then T4 (3.95cm, 7.74cm, 11.54cm and 15.48cm) and the lowest height value was observed at T3 (3.86cm, 7.72cm, 11.58cm and 15.44cm) respectively. However, in week 4 of the cold treatment, T3 (11.58 cm) recorded a higher value than T4 (11.54 cm), and in week 5, T4 (15.48 cm) recorded a higher value than T3 (15.44 cm) and T2 (15.43 cm). Based on the results obtained, the irregularities recorded may be due to rainfall interference. Comparing cold and hot water, there was no noticeable difference in terms of inhibitory effect, as *E. camaldulensis* reduced the seedling height of *Arachis hypogaea* compared to controls, which is in line with the findings of Wasihun (2013).

Table 1: Shows the seedlings' height of the hot treatment

Treatment	WAS 2	WAS 3	WAS 4	WAS 5
T1 (0%)	5.440^{a}	10.890^{a}	16.320^{a}	21.760^{a}
T2 (25%)	3.030^{c}	6.060^{c}	8.990^{c}	12.120^{c}
T3 (50%)	4.120^{b}	8.200^{b}	12.340^{b}	16.420^{b}
T4 (100%)	3.750^{bc}	7.480^{bc}	11.110^{bc}	15.00^{bc}
LSD (5%)	0.0001	0.0001	<.0001	0.0001

Data with different superscripts are significantly different ($p < 0.05$). Note: WAS means week after sowing.

Table 2: Shows the seedlings' height of the cold treatment

Treatment	WAS2	WAS 3	WAS 4	WAS 5
T1 (0%)	5.440^{a}	10.880^{a}	16.320^{a}	21.760^{a}
T2 (25%)	3.970^{b}	7.940^{b}	11.910^{b}	15.430^{b}
T3 (50%)	3.860^{b}	7.720^{b}	11.580^{b}	15.440^{b}
T4 (100%)	3.950^{b}	7.740^{b}	11.540^{b}	15.480^{b}
LSD (5%)	<.0001	<.0001	<.0001	<.0001

Data with different superscripts are significantly different ($p < 0.05$). Note: WAS means week after sowing.

Seedling girth

Comparison of seedling girth (Hot and Cold treatments)

Table 3 below shows the seedling girth values of A. hypogaea in a nursery experiment, recorded over four weeks using a hot aqueous extract of *E. camaldulensis*. The results showed a significant difference ($P < 0.05$). In (WAS2, 3,4 and 5) the widest plant girth was observed in T1 (control) (1.81cm, 1.89cm, 2.03cm and 2.17cm) respectively, followed by T3 (1.50cm, 1.22cm, 1.54cm and 1.62cm), then T4 (1.25cm, 1.18cm, 1.37cm and 1.47cm) and the thinnest girth value was observed at T2 (1.10cm, 1.09cm, 1.13cm and 1.07cm) respectively. The reduction in plant girth in the treatments compared to the control is in line with

the findings of Rao and Reddy (1984), which showed the inhibitory effect of *E. camaldulensis* on the the growth rate of some legumes. On the other hand, Table 4 below presents the seedling girth values of Eucalyptus under cold aqueous mixture; there was a significant ($P < 0.05$) difference in the treatments. In (WAS 2, 3,4 and 5) the widest plant girth was observed in T1 (control) (1.81cm, 1.95cm, 2.20cm and 2.20cm) respectively, followed by T3 (1.62cm, 1.51cm, 1.54cm and 1.52cm), then T2 (1.35cm, 1.42cm, 2.60cm and 1.47cm) and the thinnest girth value was observed at T4 (1.28cm, 1.37cm, 1.37cm and 1.51cm) respectively. However, in week 4, T2 (2.60 cm) was wider than T1 (2.20 cm) and T3 (1.54 cm). Additionally, in week 5, T4 (1.51 cm) is wider than T2 (1.47 cm). Based on the results obtained, the irregularities recorded may be due to rainfall interference. Between the cold and hot water extract mixture, there was no noticeable difference. Similarly, the reduction in plant girth in the treatments compared to the control is in line with the findings of Rao and Reddy (1984), which showed the inhibitory effect of E. camaldulensis on the the growth rate of some legumes.

Table 3: Shows the seedlings' girth of the hot treatment

Treatment	WAS 2	WAS3	WAS 4	WAS5
T1 (0%)	1.810^{a}	1.890^{a}	2.030^{a}	2.170^{a}
T2 (25%)	1.100^{c}	1.090^{b}	1.130^{c}	1.070^{c}
T3 (50%)	1.500^{ab}	1.220^{b}	1.540^{b}	1.620^{b}
T4 (100%)	1.250^{bc}	1.180^{b}	1.370^{bc}	1.470^{b}
LSD (5%)	0.0006	0.0001	<.0001	<.0001

Data with different superscripts are significantly different ($p < 0.05$). Note: WAS means week after sowing.

Table 4: Shows the seedlings' girth of cold treatment

Treatment	WAS2	WAS3	WAS4	WAS5
T1 (0%)	1.810^{a}	1.950^{a}	2.200^{a}	2.200^{a}
T2 (25%)	1.350^{b}	1.420^{b}	2.600^{a}	1.470^{b}
T3 (50%)	1.620^{a}	1.510^{b}	1.540^{a}	1.510^{b}
T4 (100%)	1.280^{b}	1.370^{b}	1.370^{a}	1.510^{b}
LSD (5%)	<.0001	<.0001	0.6323	<.0001

Data with different superscripts are significantly different ($p < 0.05$). Note: WAS means week after sowing.

Number of leaves

Comparison of the seedling number of leaves (Hot and Cold treatments)

Table 5 below shows the values for the number of leaves of *Arachis hypogaea* recorded for four weeks using aqueous extract (hot) of *Eucalyptus camaldulensis*. A significant difference ($P < 0.05$) was observed between the treatments. In (WAS 2, 3, 4 and 5) the highest number of leaves was observed in T1 (control) (20.80, 41.60, 62.42 and 83.20) respectively, followed by T3 (10.40, 20.80, 31.20 and 41.69), the least value was observed in T2 and T4 (9.20, 18.40, 27.60 and 36.80) where both are the same. The reduction in the number of leaves in the treatments as compared to the control is in agreement with the findings of Bhaskar et al. (1992) that showed the

inhibitory effect of *Eucalyptus* on the number of leaves of legumes. On the other hand, Table 6 below presents the seedling values for the number of leaves using cold Eucalyptus aqueous extract. The results showed a significant ($P < 0.05$) difference in the number of leaves across all treatments. In (WAS 2, 3, 4 and 5) the highest number of leaves was observed in T1 (control) (20.80, 41.40, 62.40 and 83.20) respectively, followed by T2 (19.60, 39.20, 58.80 and 78.40), then T3 (14.80, 29.60, 44.40, 59.20) and the least was observed in T4 (13.70, 27.80, 41.20 and 54.80). The finding is similar to that of Wasihun (2013), which stated that all the treatment levels of *Eucalyptus camaldulensis* significantly reduced the growth of maize and haricot beans, except for the 10g treatment, which is a 10% extract. Similarly, the reduction in the number of leaves in the treatments compared to the control is in agreement with the findings of Bhaskar et al. (1992), which showed the inhibitory effect of Eucalyptus on the number of leaves of legumes.

Table 5: Shows the number of seedlings with leaves subjected to hot treatment

Treatment	WAS 2	WAS 3	WAS 4	WAS 5
T1 (0%)	20.800^{a}	41.600^{a}	62.400^{a}	83.200^{a}
T2 (25%)	9.200^{b}	18.400^{b}	27.600^{b}	36.800^{b}
T3 (50%)	10.400^{b}	20.800^{b}	31.200^{b}	41.600^{b}
T4 (100%)	9.200^{b}	18.400^{b}	27.600^{b}	36.800^{b}
LSD (5%)	<.0001	<.0001	<.0001	<.0001

Data with different superscripts are significantly different ($p < 0.05$).Note: WAS means week after sowing.

Table 6: Shows the number of seedlings in the cold treatment

Treatment	WAS 2	WAS 3	WAS 4	WAS 5
T1 (0%)	20.800^{a}	41.400^{a}	62.400^{a}	83.200^{a}
T2 (25%)	19.600^{a}	39.200^{a}	58.800^{a}	78.400^{a}
T3 (50%)	14.800^{b}	29.600^{b}	44.400^{b}	59.200^{b}
T4 (100%)	13.700^{b}	27.800^{b}	41.200^{b}	54.800^{b}
LSD (5%)	0.0089	0.0111	0.0093	0.0089

Data with different superscripts are significantly different ($p < 0.05$).Note: WAS means week after sowing.

CONCLUSION

Eucalyptus camaldulensis species is claimed to be notorious for having an allelopathic effect on the growth of crops in association. Generally, the *Eucalyptus* hot aqueous extract inhibited the growth performance of the groundnut more than the cold aqueous extract in the experiment. Conclusively, the allelochemicals present in the aqueous extract of *Eucalyptus camaldulensis* suppressed all the parameters measured (height, girth, and number of leaves) in the crop species studied. This finding proves the allelopathic effect of *Eucalyptus camaldulensis* on the growth performance of groundnut.

RECOMMENDATION

It is recommended that groundnut (*Arachis hypogaea*) should not be planted close to or in association with *Eucalyptus camaldulensis* trees due to its effects (Allelopathy) on the growth of the plant species. There is a need to provide information to farmers about the right agroforestry trees to be planted on their farms.

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GROWTH RESPONSE OF *Syzygium guinense* (WATER PEAR) ON DIFFERENT SOIL TYPE IN ADUSTECH WUDIL NURSERY

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Abstract

This study assessed the growth response of *Syzygium guineense* on different soil types: sandy, loamy, and clay. The experiment was arranged in a completely Randomized Design (CRD) with three replicates. Descriptive and inferential statistics were employed to analyze collected data (Percentages, Analysis of Variance, and Duncan Multiple Range Test). sandy soil with cow dung at 3:1(T1), clay soil with cow dung 3:1(T2) loamy soil 3:1 (T3) combination of the three soils (T4, control). Two hundred seeds were planted (50 seeds for each treatment)—seed germination percentage, plant height, and number of leaves. Total fresh and dry biomass was assessed from six to twelve weeks after germination. Loamy soil treatment commencedd germination after 32 days and achieved 57% germination, which was significantly different ($P < 0.05$) from the other treatments, especially the clay soil treatment, which exhibited the lowest germination percentage of 18% and commenced germination first after 35 days. The results also indicate significant differences ($P < 0.05$) in plant height, number of leaves, fresh and dry biomass from the 6th to 12th week after germination, respectively. Loamy soil treatment yielded the best results when compared to other treatments that enhance seed germination and development of S. guineense in the the nursery.

Keywords: Treatment, CRD, *Syzygium guineense, Seed, Sandy, Clay, and Laomy, biomass*

Introduction

Syzygium is a genus of flowering plants belonging to the family Myrtaceae, comprising about 1200 species (Kuphumla *et al.,* 2017). It is widely distributed, spreading across tropical Africa, subtropical and tropical Asia, and Australia (Karunamoorthy *et al.*, 2011). Several species, such as Syzygium jambos, Syzygium aqueum, and Syzygium samarangense, are are grown and consumed for their edible fruits. Some are used in traditional medicine to treat inflammation, various allergic disorders, bronchitis, thirst, dysentery, and ulcers (Nur., 2014). Studies have also revealed that extracts of different species in the genus Syzygium exhibit antibacterial, antifungal, antioxidant, anti-inflammatory, cytotoxic, anti-HIV, antidiarrheal, anthelmintic, antinociceptive, antivirus, and anticancer activities (Francine *et al*., 2016). *Syzygium guineense* is one of the most important species in the genus *Syzygium*. It is a large, evergreen flowering plant distributed in the tropical regions of the world, including Australia, Asia, and Africa, as well as Ethiopia (Ezenyi, 2016). The plant is also widely distributed in various parts of Ethiopia (Girmay A, 2002) and is known by different local names, such as "*Dokma*" in Amharic, "*Badeessaa"* in Oromifa, and "*Duwancho"* in Sidama (Bizuayehu, 2004). Its fruits are edible, as they are known to have a higher nutritional value (Baressa A., 2016).

There are also reports that mention the potential of the tree for family diet and household food security in different parts of Africa, including Ethiopia. (Ermias L *et al,* 2011). *Syzygium guineense* (Willd.) DC. (Myrtaceae) It has a wide distribution in tropical Africa, being locally gregarious in the Guineo-Sudanian zones (Arbonnier, 2008). The tree finds many applications in traditional African medicine. Seed multiplication is a straightforward and commonly used multiplication method (Maroyi, 2008). According to Maundu *et al*. (1999), *S. guineense* is a tree whose sweet edible fruits are used. It is an important bee fodder, but its seeds are recalcitrant (losing viability within a short period of time, usually 24 hours) and highly desiccation-sensitive (Dagnachew, 2008). Therefore, they must be sown

immediately after harvest (Eyog Matig, 2006; Orwa *et al*., 2009; Maroyi, 2008).

Soil is a very important medium for the growth of vegetation. Soil provides the nutrients necessary for the growing process of plants and conserves water. Different soil types have distinct characteristics in terms of physical, chemical, and biological properties. Soil properties determine the nutrient content and the volume of water that can be stored in the soil and the root systems of vegetation, which reflect the circulation of oxygen and water movement in the soil (Schwab *et al*., 1993).

Optimal nursery management for use is lacking in Adustech Wudil, hindering the the proper domestication of this valuable tree species. A nursery study on *eucalyptus*, *acacia mearnsii, camaldulensis*, and *leucaena pallida* showed differential response of the tree species to the difference in potting substrate (Abebe *et al*., 200b) Nursery is the place where seedling are raised and managed carefully for later transplanting to the field (Opeke, 1982), it provide the means to control environmental (growth) factors to produce healthy and uniform seedlings necessary for planting activity (Doran, 1997) Successful nursery operation depends on many factors (Evans, 1986), of which selection of appropriate container pot size and soil mixture stand out among others. Optimum pot size and favorable soil conditions are indispensable for the success of a nursery in promoting normal seedling growth (Opeke, 1982; Jaenicke, 1999). Different soil types may vary in their physical, chemical, and biological properties, and different species of trees may also vary in their requirements for soil nutrients, light, and moisture. Thus, the suitability of a given soil type for a nursery depends on its properties, and this calls for a systematic study to determine the best soil for the production of the species.

Soil as a fundamental natural resource performs key environmental, economic, and social functions. These functions of soil vary over space and time, governed by soil quality. The quality of soil is its capacity to function within ecosystem and land use boundaries, to sustain biological productivity, maintain environmental quality, and promote plant, animal, and human health (Doran *et al*. 1996). High-quality soil not only produces better food and fiber but also helps to establish natural ecosystems and enhance air and water quality (Griffiths *et al*. 2010). The capacity of soil in terms of water absorption and buffering against induced changes, as well as its resistance to erosion and damage, supplying adequate rooting, oxygen, and nutrient balances to plants, is considered key indicators of soil quality (Jing et al., 2011). Soil quality changes over time, influenced by several factors, including land-use dynamics (Islam and Weil 2000; Compos et al. 2007) and natural factors such as topography (Jing et al. 2011), as well as geomorphic processes, e.g., soil erosion (Buscot 2005).

Seed viability and seedling resistance to multiple natural aggressions can be determined by biological and physiological factors specific to the species themselves (Willan, 1992; Lopez *et al*., 2000). They are essential determinants of the seminal regeneration of plant species in a natural environment (Bationo *et al*., 2001). In is the case, for example, for the water content of seeds, which affects the longevity and storage conditions of seeds (Orozco-Segovia and Vazquez-Yanes,1993). Similarly, the functional morphology of the seedlings affects their adaptability to constraining factors of the natural environment (Gorse, 1994; Ouedraogo & Alexandre, 1994; Sambou *et al*., 1994). (Ellis *et al*., 1990; Girma & Blyth, 2000). Since many tree species are threatened with extinction, it is crucial to document their seed biology (Demel, 1993). All these constraints could also impede the good germination of seeds and seedlings of *S. guineense*, a very nectariferous species, as many studies have demonstrated that this species is a highly nectariferous bee plant that benefits from pollination by insects, among which *Apis mellifera adansonii* (Hymenoptera: Apidae) is the most important (Yedomonhan, 2009; Djonwangwe *et al*., 2011). However, no data are available on the reproduction of S. guineense. Tree Crop production involves a complex interaction between the environment, soil parameters, and nutrient dynamics (Ukpong and Moses, 2001). Because of this fact, the soil must be studied in terms of its productive potential. It is also important to understand the relationships between environment and crops. Failure to understand these complexities has resulted in a lack of effective crop production and management techniques; hence, agricultural production has tended to be low. In Nigeria, and elsewhere in the tropics, extensive studies have been carried out on many tree crops, including cocoa (Ekanade 1985a, 1985b, 1988), kola nut (Ekanade and Egbe, 1990), rubber (Pushiparajah, 1977), oil palm (Aweto and Ekuigbo, 1994; Ogidiolu, 2000), and cashew (Aweto and Isola, 1995). So far, the

findings have shown that different tree crops have different interactions with soil properties. Absent in the literature are the interrelationships between Syzygium guinense and the soils. The tree itself has other commercial importance. Recent trends indicate a decline in emphasis on its cultivation among peasant farmers, either due to its long maturity period or poor yield (Opeke, 1978). This study aims to examine the capacity of different soils, intending to identifying the best soils that substantially influence the growth, hence, the productivity of the crop. The outcome of this study should form the basis for formulating a nursery and management strategy for the cultivation of the tree crop in Nigeria.

Problem statement

Although human activities have led to the loss of several tropical forests, studies have also documented the expansion of tropical forests into open vegetation areas, such as savannas and woodlands, in many parts of the world (Geiger *et al.* 2011). Nucleation is an important model of forest expansion (Yarranton and Morrison 1974), in which trees in open vegetation act as nuclei for the colonization of forest trees, leading to the formation of forest patches (Favier *et al.* 2004)

Another reason for the loss of indigenous knowledge and forest degradation is human interference, including the expansion of agricultural land, grazing, firewood collection, and drought (FAO, 2010). It has been known that there is a high degree of exploitation of the plant for different purposes. They were also able to identify the factors considered as threats and rated agricultural expansion and selective cutting for construction material as the principal threats to *S. guineense*. Vivero (2001-02) argued that the major reasons for the high rate of forest clearing in most forest areas are the increasing intensive use of land for agricultural and livestock production. According to the author, tree cutting for fuel wood and construction materials is also mentioned as a major cause of deforestation.

Low soil fertility is widely recognized as a major obstacle to improving agricultural productivity in sub-Saharan Africa. In most regions of Africa, soil fertility degradation is caused by three interlinked factors: (Ajayi, 2007) the breakdown of the traditional fallow system as a result of an increase in human population and decreasing per-capita land availability, which forced farmers to crop continuously and encroach on marginal lands in search of more fertile lands; (Ajayi and Kwesiga, 2003) inadequate adoption of soil management investments such as conservation or crop residue incorporation; and (Ajayi and Akinnifesi, 2007) sub-optimal use of fertilizers by a majority of smallholder farmers due to high cost and constraints to access them. The situation became more challenging after the removal of farm input subsidies and the collapse of para-state agricultural input marketing agencies, which began in the 1980s. For example, after the removal of fertilizer subsidies in Zambia, the price ratio of nitrogen to maize increased by 400 percent, resulting in a 70 percent decline in fertilizer use by smallholder farmers (Howard and Mungoma, 1996). Given the strong linkage between soil fertility and food insecurity, addressing the decline in soil fertility remains a crucial challenge for those formulating Africa's development policy agenda (NEPAD, 2003). There is a need for technological options that replenish soil fertility as quickly as possible for a range of ecologies and agricultural systems and that are suitable for different types of farm households. Fertilizer tree systems (FTS) are one option that has been developed to meet such challenges.

The rate of deforestation is increasing rapidly in Nigeria, and the efforts made to halt this trend are minimal, which makes the situation both worse and alarming (Elias Taye, 2004). Forests are being destroyed even before they have been surveyed, described, and studied thoroughly (Demel Teketay, 1993). Legesse Negash (1995) pointed out that some decades ago,, Nigeria was covered by various indigenous tree species, including Podocarpus, Acacia, and wild olive, among others. However, increasing wood harvests reduces the amount of carbon sequestered and stored in forests at least for decades, thus resulting in a trade-off between carbon sequestration and substitution (Helin *et al*. 2013).

Justification of the study

Reforestation of degraded lands through the plantation of native species depends on the possibility of raising seedlings either from seeds or vegetative propagules (Demel, 1993). Access to seeds and seedlingss, as well as storage problems, limits the use of many potentially high-value indigenous species in tree planting and conservation programs. Forests and soils play a crucial role in climate change mitigation, serving as major carbon sinks that remove approximately one-quarter to one-third of the CO2 emitted to the atmosphere (Le

Quéré *et al*., 2018). Besides that, forests provide renewable materials and energy which can be used in place of non-renewable materials and energy. Substitution effects caused by replacing emission-intensive materials with increased production of wood products and fuels offer a potential strategy to decrease greenhouse gas (GHG) emissions into the atmosphere (Werner *et al*. 2010; Hagemann *et al*., 2016; Geng *et al*., 2017a). In most cases,, the manufacturing of wood products and fuels causes fewer emissions compared to non-wood alternatives (Sathre and O'Connor 2010; Rüter *et al*. 2016; Leskinen *et al*. 2018).

Forests are a crucial sink for atmospheric carbon and could release that carbon upon deforestation and degradation (Lim et al., 2013). Therefore, the dynamics of biomass growth are important to study, especially about future environmental changes (Fang *et al*., 2014). The forest ecosystem can also become a source of contamination for several ecosystems in the context of post-accident (watershed, leaching leading to contamination in aquatic and agricultural environments (Fukuyama *et al*., 2005; Karki and Shibano, 2006), groundwater contamination (Bugai *et al*., 1996), fire problem reemitting particles or gases in the Atmosphere (Evangeliou *et al*., 2016).

Aim and objectives of the study

The broad objective of this research is to determine the best soil type for Syzygium guinense seedling production in a nursery, among sandy, loamy, and clay soils, with a control as a mixture of the three different soil types.

Specific objectives

1. To assess the early growth performance of the *Syzygium guinense* seedling

2. To determine the germination percentage of the *Syzygium guinense* seedling.

3. To determine the number of leaves and height of the Syzygium *guinense* seedling.

4. To measure the total fresh and dry biomass of the seedling.

Materials and methods

Description of the study area

This study was carried out at Aliko Dangote University of Science and Technology, Wudil, Kano State. Wudil Local Government is among the 44 local governments of Kano State, and it is located between the latitudes 12˚ 58˚ N and longitudes 8˚C 25'8. (NIPOST, 2009) It's bordered to the North by Gaya Local Government and to the south by Garko Local Government area, to the west by Rano Local Government area, and the east by Warawa Local Government. The area fallss under the landform unit of the Kano region, known as the Plain of Hausa Land (Olofin, 2008). The climate of the area is classified as dry and wet.the temperature of the area is warm to hot. Still, there is slight of cold period in November to February, December to January are considered the coolest months with the mean value ranging from 12˚C to 21˚C, while April to May are considered the hottest months with temperature of at least 3˚C (Olofin, 2008) the climate is mainly semiarid, characterized by annual rain fall of 850mm (Olofin, 2008).

Materials

Sandy soil, loamy soil, clay soil, Thread, measuring cup, wheelbarrow, weighing machine, Identification tag, Book, Pen, hoe, seed, Shovel, Head pan, Cow dung, Watering can, Polythene bag, Meter rule, Oven dry, Analytical balance.

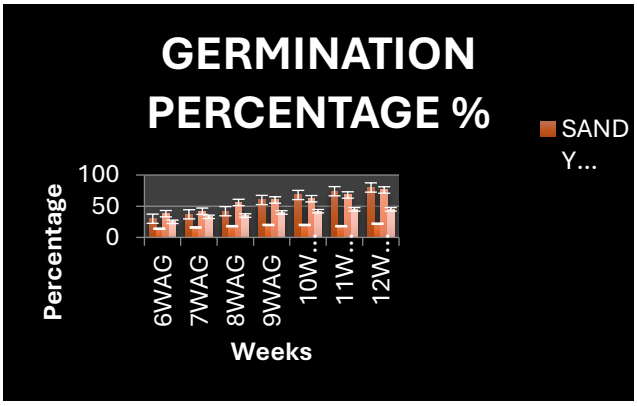
Data Collection and Analysis

Weekly observations were made to determine the response of *Syzygium guinense* seeds to different soils. Data on growth variables were measured, including seedling heights, which were measured from the soil level to the tip of the seedlings using a meter rule. Leaf numbers were counted, and the mean number of leaves per replicate was recorded. The Total fresh biomass was measured using an analytical balance, and the Total dry biomass was measured in the lab after setting the fresh seedling in an oven at 105˚C for 30 minutes. Data collected on seed germination and growth variables (seedling heights, number of leaves, Total fresh biomass, and Total dry biomass) were subjected to descriptive statistics (percentages, means, and standard deviations) and inferential statistics (analysis of variance (ANOVA)) to analyze data collected in the study area. Where significant differences occurred between the treatment means, the Duncan multiple range test method was used to separate the means.

RESULTS

Growth response of *S. guinense* on germination percentage

The result of the seed germination percentage revealed that the loamy soil treatment recorded the highest mean percentage of germination of 57% which was recorded from the 6th week to the 12th week after germination. It was observed that clay soil treatment recorded the least mean percentage germination with 18% respectively.



Source: Field Survey 2023

Growth response of *S. guinense* on the number of leaves

Table 1 Number of leaves at week (12) shows that the significance (P>0.05) difference was only observed in treatment two, T2 (clay soil treatment), but the rest of the treatments were not statistically significant (p<0.05) difference observed respectively.

Growth response of *S. guinense* on seedling height

The seedling height shows that there is no statistically significant (P < 0.05) difference across all the treatment values observed at week 12 (Table 2). Only a T2 (clay soil treatment) significance difference (P > 0.05) was recorded, respectively.

Growth response of *S. guinense* on total fresh and dry biomass

Total Fresh and dry biomass shows no statistically significant (P<0.05) differences across all the treatment values obtained (Table 3). except T2 (clay soil treatment) (0.72g), (0.11g) respectively.

Table 1: Number of leaves recorded of *Syzygium guinense within the treatments.*

Treatments	6wag	7wag	8wag	9wag	10wag	11wag	12wag
Sandy soil	1.08^{ab}	2.94^{ab}	4.72^{a}	6.98^{a}	10.56^{a}	14.64^{a}	18.36^{a}
Clay soil	0.50^{b}	1.28^{b}	1.96^{b}	2.60^{b}	2.74^{b}	3.50^{b}	4.26^{b}
Loamy soil	1.64^{a}	3.88^{a}	6.88^{a}	9.64^{a}	11.34^{a}	15.14^{a}	17.94^{a}
Control	1.30^{a}	2.70^{ab}	5.78^{a}	8.92^{a}	10.90^{a}	13.34^{a}	16.52^{a}
P value	**3.50**	**3.13**	**4.67**	**6.44**	**7.96**	**8.83**	**9.23**

Source:Field data

Table 2: Seedling height recorded of *syzygium guinense* within the treatments.

	SEEDLING HEIGHT (cm)						
Treatments	**6wag**	**7wag**	**8wag**	**9wag**	**10wag**	**11wag**	**12wag**
Sandy soil	0.69^{a}	1.59^{a}	2.85^{a}	4.21^{a}	5.96^{a}	7.90^{a}	9.18^{a}
Clay soil	0.21^{b}	0.52^{b}	0.92^{b}	1.13^{b}	1.16^{b}	1.30^{b}	1.44^{b}

Loamy soil	1.03[a]	2.29[a]	3.71[a]	5.04[a]	6.40[a]	7.83[a]	9.52[a]
Control	0.98[a]	2.09[a]	3.81[a]	5.18[a]	6.35[a]	7.54[a]	8.56[a]
P value	**8.43**	**7.34**	**7.36**	**9.66**	**13.11**	**15.88**	**17.55**

Table 3: Fresh and dry biomass recorded of *Syzygium guinense* at 12 weeks.

Treatment	Fresh biomass(g)	Dry biomass(g)
Sanday soil	4.19[a]	1.39[a]
Clay soil	0.72[b]	0.11[b]
Loamy soil	4.47[a]	1.43[a]
Control	4.16[a]	1.05[a]
P value	**0.60**	**0.27**

Discussion

The final percentage of germination (PG) is the percentage of seeds that germinated under experimental conditions **(Tang *et al*., 2007),** the result of this study in germination shows significance (P>0.05) difference across the treatments (figure 1) the Sandy soil has the highest germination percentage (57%) in 6th week—followed by loamy soil with (56%). However, the clay soil resulted in the lowest germination rate (18%), which might be due to its heavier and compacted nature, which can limit water and air penetration (Alberty et al., **1984).** In contrast, the shoot length and seedling height were found to be highest in clay soil due to the presence of a high ratio of cow dung, although germination of seeds was found to be (90%) in clay soil according to Raman and **Laura (2015) b**ecause clay soil with a high content of farmyard manure or cow dung can produce well.

The highest number of leaves of S. *guineense seedling* was recorded in loamy soil with a value of 64), followed by sandy soil with the same value obtained (Table 1). Lastly,, clay soil was recorded with the least number of leaves in this finding. This finding is contrary to Abou Hussien et al. (2010), which stated that soil in all growth parameters might be attributed to the ability of clay soil to support plants, as it provides favorable water conditions and a higher content of available macro and micronutrients compared to sandy soil. And another study conducted in south Africa also found that *S. guineense* shows better growth performance in sandy loam soil compared to clay soil (**Mashingaidze *et al.*,2019**) the study noted that, the sandy loam soil has level of organic matter and nutrients which contributed to better growth and developments of the tree which agrees with current finding.

The result of the seedling height of *S.guineense* implied that sandy and loamy soil were found to have the highest value of seedling height, with 64cm recorded, while clay soil was found to have the least value of the seedling height of 48cm (Table 2). This finding is in agreement with a study conducted by **Adomako *et al. (*2017)** in Ghana, which examined the growth response of *S.guineense* on three soil types, including loamy soil. The study found that the trees grown on loamy soil had the highest mean height and stem diameter compared to those grown on clay soil.

Both the total fresh and dry biomass of seedling S. *guineense* were significantly (P>0.05) influenced by the major effect of different soil composition. Loamy soils were found to have the highest mean values of fresh weight (4.47g) and dry weight (1.43g), while clay soils found to have the least total fresh weight (0.72g) and dry weight (0.11g), respectively. It might be due to the nutrients of the soil. It was suggested by **Medany*et al., (*2009)** that the increase in dry biomass of the seedling might be responsible for the beneficial effect correct medium composition has on soil physio-chemical characteristic.

The result of this current experiment on early growth performance was found in lo amy soil. This finding is in agreement with another study conducted by Omokhua *et al. (2014) in Nigeria, where the growth and yield of S. guineense were evaluated on different soil types, including loamy soil*. The study found that trees grown on loamy soil have the highest mean height and stem diameter compared to those grown on sandy and clay soils. The researchers attributed this to the better nutrient retention capacity of loamy soil, which provided the tree with adequate nutrients for growth.

Summary

A study was conducted at the nursery of the Forestry Department, Aliko Dangote University of Science and Technology, Wudil, ADUSTECH. The study was to determine the growth response of *S. guineense* on different soil types. A total of 200 seeds were used in the experiment. Sandy soil, clay, loamy, and control treatments were replicated 50 times each for T1, T2, T3, and T4, respectively. Both the experimental materials were sourcedd from Wudil town and the university premises in Kano State, Nigeria. Experimental seeds were allocated to a completely randomized design (CRD), and treatments were replicated 50 times. The experiment lasted for twelve weeks, during which the results show that there was a significant difference ($P > 0.05$) in T2 for all the parameters determined, which are germination percentage (%), number of leaves, seedling height (cm), and Total fresh and dry biomass (g), respectively.

Conclusion

In conclusion, *Syzygium guineense* can grow well on loamy soil, provided the soil has adequate moisture and nutrients. The growth response of the trees on loamy soil can be higher compared to other soil types due to its higher water and nutrient retention capacity. However, other environmental factors, such as temperature and rainfall, also play a significant role in the growth and yield of the trees. However, *S. guineense* has been shown to have a positive growth response on sandy soil, especially in regions with sufficient moisture and nutrients. However, other factors, such as soil leaching and nutrient content, can also affect the growth of the species on sandy soil. On the other hand, clay soil is characterized by its high water-holding capacity, low permeability, and nutrient retention. These properties can influence the response of *Syzygium guineense* when grown in such soils.

Recommendation

1. Loamy soil is recommended as the most suitable soil for the production of *S.guineense* in the nursery for plantation purposes.

2. Tree farmers or nursery owners, who are interested in the production of *S. guineense* seedlings, should be advised to use loamy soil to ensure early germination of the seeds

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Theme: *Forest Sustainability in the face of climate change and insecurity: Innovative technologies and Strategies*

GEO-SPATIAL LANDSCAPE MANAGEMENT OF IBADAN, NIGERIA

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Abstract
Managing urban landscape requires the integration of an extensive range of data on eco-environmental processes. Urban major land use is classified into three categories: residential, recreational, and industrial areas. This paper evaluated urban changes resulting from rural-urban migration, specifically in terms of the urban population. This paper applied remote sensing and GIS for a spatial analysis system to manage the urban landscape in Ibadan, Nigeria. Landscape metrics (indices) quantifying spatial patterning, land cover classification, and landscape mosaics of the geographic area were involved in the analysis. The change trend from 1984 to 2023 (39 years) indicated that 2,547.23202 ha (50%) of the thick forest in 1984 had reduced to 1,276.0857 ha (50%) in 2019. At the same time, new development increased from 617.458865 ha (14%) in 1984 to 2,135.2500000 ha (43%) in 2021. The images were classified using a tailored classification scheme, achieving accuracies of 93.82% and 95.27% for the 1984 and 2000 images, respectively. The Markov Change Model was used to project into 2050 to determine the change pattern. Urban planning and facility management are crucial, particularly in involving environmental impact assessments. The urban landscape should include allotment gardens, industrial sites, waste ground, waterfronts, school playgrounds, historic parks, and nature reserves, among others. Planting trees along roads, rivers, and streams, and greening compounds instead of full concrete, is also advocated. It significantly reduces air pollution, heat, and noise, enhances quality of health, and recreational and cultural values for urban citizens. The study also considered the protection of erosion and flood-prone areas with vegetation. To accomplish these aims, a choice of plants (trees, shrubs, flowers, and grass) must be selected for planting.

Keywords: geo-spatial application, urban, landscape management

INTRODUCTION

Pressures on forests, especially in the tropical world, to provide economic resources have been increasing rapidly as a consequence of the burgeoning population in the region. It has led to unabated deforestation, which has been recognized as one of the major drivers of biodiversity loss and a threat to the global ecological lung's existence. Monitoring urban growth using satellite images provides a means for acquiring imagery regularly presenting timely information that can be combined with ancillary data to monitor urban change and distinguish expansion models (Khorram 1987; Harris and Ventura, 1995). Acevedo *et al*. (1999) utilized satellite images, aerial photography, and historical maps to create a database that represented land use change, enabling the modeling of urban growth and land use change for predicting growth scenarios.

Urban remote sensing applications primarily involve land use/cover classification and change detection. Classification studies focus on distinguishing areas according to a predefined land use/cover classification scheme, while change detection applications are concerned with producing sensible information about land use/cover changes and monitoring urban expansion to prepare policies that foresee potential problems resulting from growth. Forster (1983) claimed that the first attempt to examine the full potential of aerial photography in urban analysis was in 1948 by Branch (Branch, 1948).

Urban growth definition

There are many tangled terms used in the context of urban studies, such as urban development, urban growth, and urbanization. It is instructive in this introduction to draw a clear and firm distinction among these terms. Clark (1982) defined urban development as the process of emergence of a world dominated by cities and urban values, with the main processes of urban development being urban growth and

urbanization. Urban growth is a spatial and demographic
process and refers to the increased importance of towns and cities as concentrations of population within a particular economy or society. At the same time, urbanization is a spatial and social process which refers to the change of behaviour and social relationships which occur in society as a result of people living in towns and cities (Clark 1982). This study aims to address urban growth, encompassing its spatial and demographic aspects.

Integration of Remote Sensing and GIS

Mesev (1997) claimed that the term "Remote sensing and GIS integration" indicates that The integration between GIS and Remote Sensing can be fruitful. Numerous studies have suggested that the spatial analysis and cartographic modelling techniques used in GIS, and the digital image processing techniques used in remote sensing, should be combined for enhanced analysis in urban applications (Hutchinson, 1982; Richards *et al.,* 1982; Newkirk and Wang, 1989; Wang and Newkirk, 1987). The land mass, particularly in developing countries, is a dynamic entity whose elements are constantly evolving. For example, when forests are cut down, agricultural land is converted, and roads and houses are built. Consequently, urban land information stored in GIS is only a static model of the real world for a particular period and must be regularly updated. Satellite data are superior in this case because they possess a higher temporal resolution, which has the potential to monitor dynamic changes within a GIS. An urban information system, therefore, when combined with up-to-date remotely-sensed data, can greatly improve the efficiency of change detection, map compilation, and revision (Seong 1994). Urban planning encompasses a range of functions, scales, sectors, and stages. In general, the functions of urban planning can be classified into general administration, development control, planning making, and strategic planning. General administration and development control are relatively routine planning activities, whereas planning making and non-routine strategic planning are undertaken much less frequently. The scale of the planning area covered can range from an entire city to a sub-region of a city, a district, or a street block. The most frequently involved sectors in urban planning are land use, transportation, housing, land development, and environmental management. At each scale of planning,, there are different stages: the determination of planning objectives, the analysis of existing situations, modelling and projection, the development of planning options, the selection of planning options, plan implementation, and plan evaluation, monitoring, and feedback. Different functions, scales, sectors, and stages of urban planning utilize GIS in various ways.

Land suitability maps are very useful in the development of planning options. They can be used to identify the solution space for future development (Yeh and Chow 1996). The association of spatial optimization models with GIS can help formulate and develop planning options that aim to maximize or minimize specific objective functions (Chuvieco, 1993). The simulation of different development scenarios using GIS can aid in developing planning options (Landis, 1995). The rapid sprawl of Ibadan city has encroached on available forested areas, savannas, farmland, fallow lands, and river floodplains. In reality it, forests and wetlands have been degraded. In the Eleyele wetland, there has been a constant loss; an estimated 66 percent of the wetland's riparian forests were lost between 1984 and 2014 due to urban expansion, and the loss continues (Tijani et al., 2012). Therefore, investigation of both urban population and the physical expansion of the city give a clear picture of the pattern of urban growth and the need to catalyse or control further development as the urban growth is often accompanied by major social, economic, and physical problems such as urban poverty, the high demand for housing, infrastructure, urban and social services, environmental degradation, the depletion of natural resources, and air and water pollution (Seong 1994). Thus, there is a need to Monitor the urban sprawl of Ibadan. Study the population trends in the city. Establish a relationship between sprawl and population density to determine the pattern of population distribution. The increased demand for land in Ibadan has led to a gradual decline in forest cover. It has resulted in increased land consumption for other purposes, as well as modifications and alterations in the status of her land use and land cover over time, without any detailed and comprehensive attempt to evaluate these changes. Deforestation as practiced in this area presents multiple societal and environmental problems. The long-term effects and consequences of this deforestation are almost certain to jeopardize life. Some of the consequences may include exposure of the catchment area, which can lead to dryness. Siltation can occur. In 2005 the urban population of the world

numbered 3.2 billion people (49 percent of total population), by 2008 half the world's population will live in urban areas. By 2030, 4.9 billion people (60 percent of total population) are projected to live in urban areas (United Nations, 2006). Urbanization is the transformation of the landscape and movement of human population from open rural areas to centers of development. Urban sprawl or expansion is one form of land use and land cover change (LUCC) in which rural areas are transformed into urban areas.

The objectives of LUCC research are detecting temporal and spatial changes in landscapes, evaluating the processes of change, and understanding the environmental impact of change. The integration of remote sensing and Geographic Information Systems (GIS) is an effective method for detecting and evaluating LUCC in the form of urban sprawl (expansion) (Mundia and Aniya, 2005; Wu *et al.,* 2006). Landscape metrics (indices) are numeric measurements that quantify spatial patterning of land cover patches, land cover classes, or entire landscape mosaics of a geographic area (McGarigal and Marks, 1995). The convergence of GIS, remote sensing, and database management systems has enabled the quantification, monitoring, modeling, and subsequent prediction of urban sprawl (Sudhira *et al*., 2004). The lines between remote sensing and GIS have become indistinguishable. Geospatial data is integrated into multiple stages of remote sensing image classification. GIS is used to perform numerous functions, extracting information from remote sensing data, and is also utilized in evaluating the factors of landscape dynamics and producing landscape metrics. In the future, the lines between landscape ecology and remote sensing-based change detection will become indistinguishable. The processes that produce dynamic landscapes will be better understood, and modeling and predicting landscape dynamics will become more accurate, leading to a deeper understanding of the environmental impacts of landscape dynamics. Spatial modelling is used more in strategic planning. General administration employs mainly data management and visualization.

The object of this study is to examine the integration of GIS and remote sensing for application

In urban growth effects on Ibadan South-West Local Government, Oyo State.

The following are the objectives;

I. To map out the different land use/land cover and their spatial distribution

ii. To quantify and map out the changes from 1984 to 2023 using LANDSAT images.

iii. Examine the specific human activity types responsible for the changes.

iv. To demonstrate the capabilities of GIS in the area of classification and overlay in the study of deforestation.

v. To model/predict possible future changes.

MATERIALS AND METHODS

Study area

Ibadan, the capital city of Oyo state, Nigeria, is located on seven hills (average elevation 700 feet, 200 meters) about 100 miles (160 km) from the Atlantic coast. Ibadan is located between latitude 7°23'47''N and longitude 3°55'00''E. It is one of the most populous cities in Nigeria. The density of Ibadan is 985.13/km^2 (2,551.5/sq mi). The economic activities of Ibadan include agriculture, commerce, handicrafts, manufacturing, and service industries, among others. Although the city's farming population has declined, it remains substantial for an urban area. Many cultivators are part-time farmers who augment their earnings with other work.

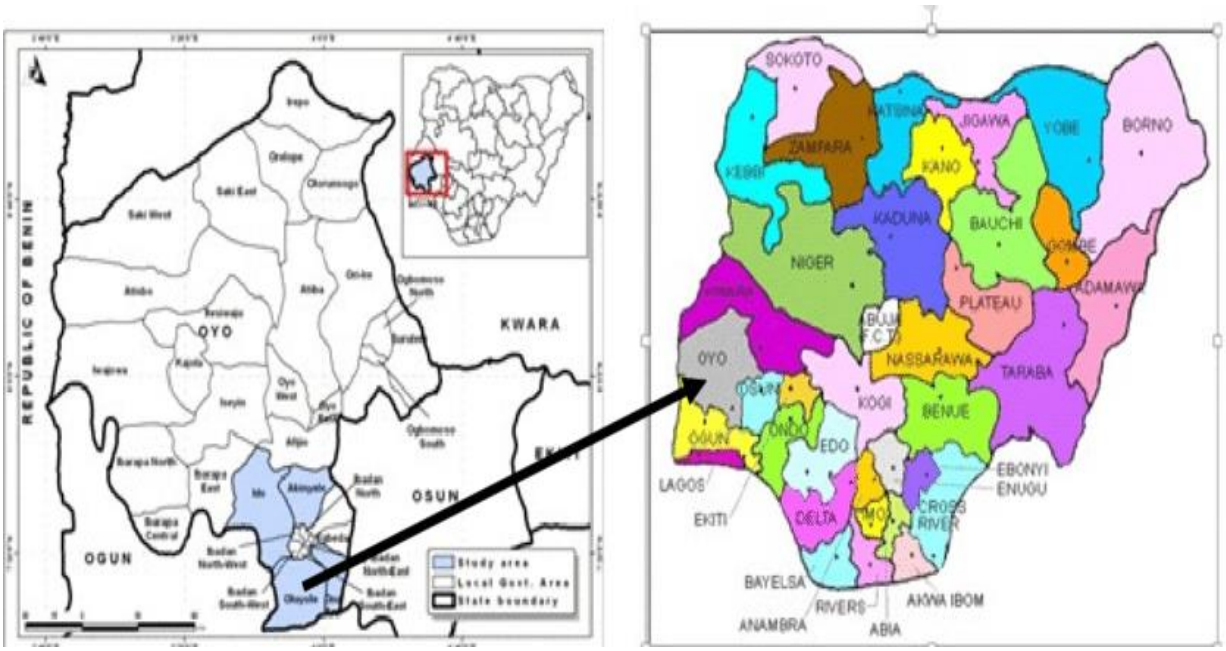

Figure 1: Ibadan South-West Local Government, Nigeria.

Data collection

Data collection is the first and most critical stage of any research or study, as this step may control the direction of the research. In this study, data of different types were collected from varying sources. Data collection is a complicated task, especially for a developing country. Many tough security checks have to be done, even for "unimportant" data. Data costs are very expensive compared to similar applications in developed countries, and they must be undertaken through complicated procedures that consume long periods. In addition, it may be not easy to get up-to-date data. Lastly, it is essential to verify the accuracy of this data before use. The following sections provide a comprehensive description of the data collected for this study.

Characteristics of Landsat TM

Landsat TM data has a 30-m ground spatial resolution cell for all bands except band 6, which has a 120m spatial resolution. Although the Landsat TM bands are finely tuned for vegetation discrimination, other applications benefit from the enhanced characteristics of Landsat TM. Band one is the best for bathymetry investigations. Bands 5 and 7 have proven to be extremely valuable in discriminating rock types. Meanwhile, band five is used to differentiate between snow and cloud-covered areas. Additionally, band six is useful in thermal mapping (Lillesand and Kieffer, 1994).

Modelling and projection

A key function of planning is projecting future population and economic growth. GIS can be used for prediction and projection (Longley *et al*. 1994). Spatial modelling of spatial distributions enables the estimation of the widest range of impacts of existing population trends, as well as economic and environmental changes. For example, a range of environmental scenarios can be investigated by projecting future demand for land resources from population and economic activities, modeling the spatial distribution of such demand, and then using GIS map overlay analysis to identify areas of conflict.

Data acquisition

Data are observations we make from monitoring the real world, collected as facts or evidence that may be processed to give them meaning and turn them into information. Data can therefore be said to be the lifeline of any study, most especially remote sensing and geographic information systems. For this study, data were collected from multiple sources. Since the nature of land cover monitoring requires images from different time periods, and change detection analysis is carried out most effectively with at least three images

of the study area, three Landsat ETM+ Satellite images of the study area were acquired in 1984, 2000, and 2023, with a a spatial resolution of 30m. Other ancillary data, such as topographic maps, were also used. All the images were obtained from NASRDA in `Table 1 below.

Table 1: Data source

SNo.	Data type	Date of Production	Scale	Source
1.	Landsat image	2023	28.5m TM	Internet
2.	Landsat image	2000	28.5m TM	Internet
3.	Landsat image	1984	28.5m TM	Internet

Software Used in the Research

- ArcGIS 10.1 is used in data processing and displaying
- Idrisi Selva is used to develop land use and land cover classes and for change detection analysis
- Microsoft Excel
- Microsoft Word is used for presentation

Methods of Data Analysis

- Calculation of the area in hectares of the resulting land use land cover area for the time series.
- Markov chain analysis for change prediction
- Maximum likelihood classification
- Land consumption rate and absorption coefficient

Development of Classification Scheme

It is based on a brief reconnaissance survey with additional information from previous research in the study area. The classification developed represents the land use and land cover with code numbers as listed in Table 2 below.

Table 2: Classification code of land use and land cover of Ibadan South-west LG

Code	Categories
1	Thick forest
2	Developed area
3	New developed
4	Forest land

RESULTS

The developed area alone accounts for more than 40% deforestation in the year 2023, and vegetation accounts for about 38% in the study area for the last year under consideration. The deforestation trend between 1984 and 2023 (39 years) showed that 2,547.23202 ha (50%) of the thick forest in 1984 had reduced to 1,276.0857 ha (50%) in 2023. While new developments increased from 617.458865 ha (14%) in 1984 to 2,135.2500000 ha (43%) in 2021, as shown in Table 3 below. All these activities were leading to the degradation of the forest, which is known as deforestation. The comparison of the land use land cover statistics was computed to identify the percentage change, trend, and rate of change from 1984 to 2023 as shown below in Table 3 and Figure 2, respectively.

Table 3: Percentage Change Trend of Land Use Land Cover of Ibadan South-west LG from 1984 to 2023

	1984		2000		2023	
Categories	Area(ha)	%	Area(ha)	%	Area(ha)	%
Thick forest	2547.23202	50	1498.9999000	30	1276.085675	22
Developed land	820.9410750	16	647.9382500	13	857.7000000	19

New developed	617.458865	14	1952.1616500	39	2135.2500000	43
Forest land	995.9037150	20	882.4358750	18	712.5000000	16
TOTAL	**4981.535675**	**100**	**4981.535675**	**100**	**4981.535675**	**100**

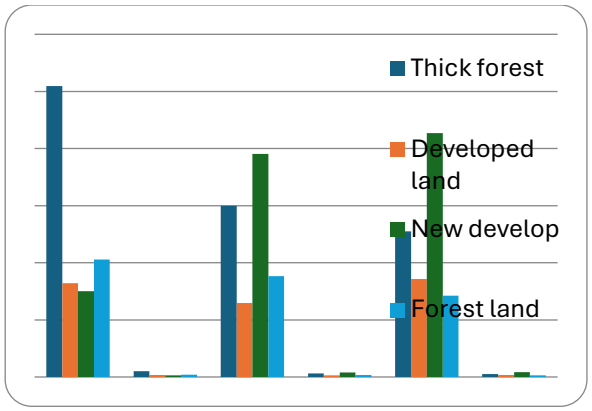

Figure 2: Graphical representation of land use land cover for 1984, 2000, and 2023

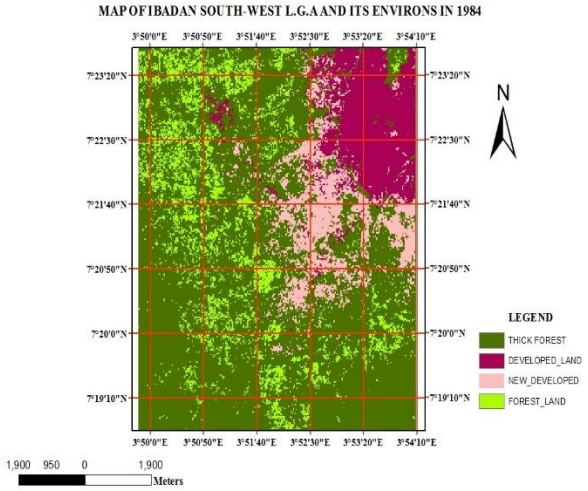

Figure 3: Ibadan South-West Local Government and its Environs in 1984

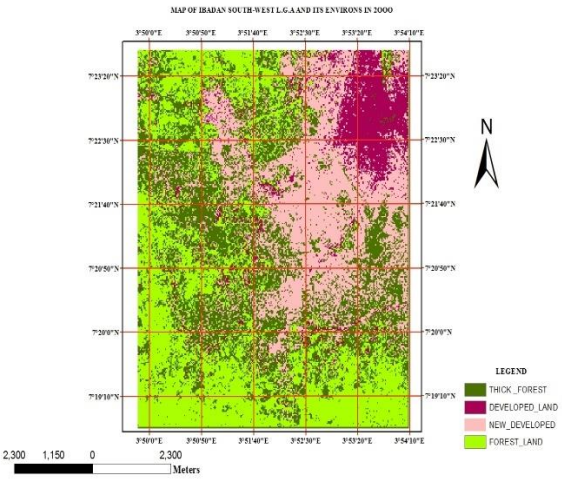

Figure 4: Ibadan South-West Local Government and its Environs in 2000

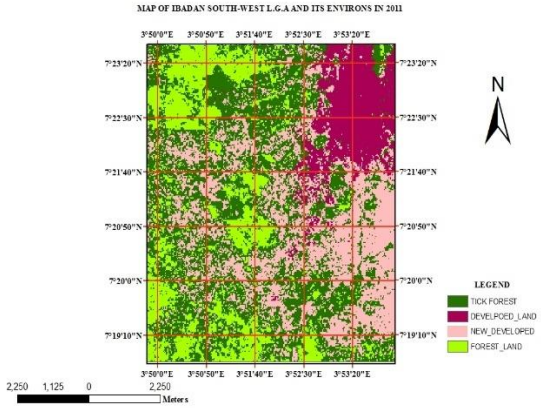

Figure 5: Ibadan South-West Local Government and its Environs in 2023

Table 4: Population Figure of Ibadan in 1984, 2000, and 2023

Year	Population figure	Source
1984	11,210,000	http//books.mongabay.com/population
2000	17,310,000	http//books.mongabay.com/population
2019	24,100,000	http//books.mongabay.com/population
2025(projected)	27,910,000	http//books.mongabay.com/population

Markov Operation

It is simply an operation in which the future state of a system can be modeled purely based on the immediately preceding state. Markov chain analysis describes land use change from one period to the next and uses this as the basis for projecting future change. The Markov module, under change and time series analysis, was used in GIS analysis with Idrisi Selva. The first image (1984) is the earlier image, and the second image (2000) is the latter image. The number of times between the two images and the number of the projected year from the second image were also input. Fourteen years were used for both numbers of periods. Row category represents land use land cover classes in 2000, while the column category represents 1984 classes as described in Tables 5 and 6 below.

Table 5: Markov 1984/2000
Given: Probability of changing to:

Classes	**1**	**2**	**3**	**4**
1	0.5561	0.4426	0.0013	0.0000
2	0.0233	0.9124	0.0400	0.0243
3	0.0368	0.1413	0.7854	0.0365
4	0.0314	0.3621	0.5600	0.0465

Table 6: Markov 2000/2023
Given: Probability of changing to:

Classes	1	2	3	4
1	0.3632	0.2707	0.3462	0.0199
2	0.2079	0.5461	0.2165	0.0295
3	0.1548	0.4264	0.3976	0.0212
4	0.5521	0.3411	0.1254	0.0186

DISCUSSION

The urban physical expansion and change were detected using Landsat satellite images. The satellite images of 1984, 2000, and 2023 were first geo-referenced, achieving a very small RMSE that provided high-accuracy data for satellite image analysis. Then, the images were classified using a tailored classification scheme, achieving accuracies of 93.82% and 95.27% for the 1984 and 2000 images, respectively. This high accuracy enabled the detection of land use/cover changes with high confidence using a post-classification comparison method. One of the most significant findings here is the loss of cultivated land to urban expansion. If the current loss rates continued, 75% of green lands would be lost by the year 2050. These hazardous rates call for an urban growth management policy that can preserve such valuable resources to achieve sustainable urban development.

CONCLUSION

A range of environmental scenarios has been investigated through the projection of future demand for land resources from population and economic activities, modeling of the spatial distribution of such demand, and then using GIS map overlay analysis to identify areas of conflict. GIS has been found useful to model different development scenarios. It can display the modeling of results in graphical form, making them easy to communicate to decision-makers. Policy makers and planners can use such information to formulate different planning options and help guide future development, thereby avoiding such environmental conflicts. Urban planning and facility management are crucial, particularly when involving Environmental Impact Assessment. The urban landscape should include allotment gardens, industrial sites, waste grounds, waterfronts, school playgrounds, historic parks, and nature reserves, among others. Planting trees along roads, rivers, and streams, as well as greening compounds instead of full concrete, is also advocated. It significantly reduces air pollution, heat, noise, enhances the quality of health, and recreational and cultural values for urban citizens.

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Theme: *Forest Sustainability in the face of climate change and insecurity: Innovative technologies and Strategies*

ANALYSIS OF VEGETATION COVER CHANGES IN KUMOTSO LOCAL GOVERNMENT AREA, KANO STATE, NIGERIA

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ABSTRACT

This study examines vegetation changes in the Kumbotso Local Government Area of Kano State over a 24-year period, utilizing GIS, remote sensing, and community-based data. Interviews were conducted with residents who have lived in the area for over 20 years to provide local context to the spatial analysis. Landsat satellite images from 2000, 2012, and 2024 were processed using supervised classification to assess land use and land cover dynamics. The analysis revealed that vegetation cover declined from 18.73% in 2000 to 5.43% in 2024, while built-up areas increased from 10.66% to 42.62%. Sparse vegetation also declined, serving as a transitional category. Respondents attributed these changes to urban expansion, population growth, and weak land-use management. The study highlights the importance of sustainable urban planning, reforestation, and enhanced enforcement of land-use policies to prevent further vegetation loss in Kumbotso.

Keywords: Vegetation cover change, GIS, NDVI, remote sensing, Kumbotso, land use, Land cover change.

INTRODUCTION

Vegetation cover refers to the proportion of land covered by vegetation relative to the total area of a given site, such as a district, watershed, or park. It is typically expressed as a percentage and encompasses various plant types, including tree canopies, shrubs, and ground vegetation. Vegetation cover loss refers to the reduction in the extent, density, or health of plant cover over time, often driven by processes such as deforestation, urban expansion, and climate change (Hansen et al., 2013). Vegetation cover loss is influenced by the interplay of natural and human-induced drivers. Climate change, characterized by rising global temperatures and shifting precipitation patterns, has intensified vegetation stress, particularly in arid and semi-arid regions (Mohammed et al., 2015).

Human activities remain the dominant drivers of vegetation loss, with deforestation and land-use conversion accounting for the largest share of decline (FAO, 2020). Large-scale agriculture, infrastructure expansion, and urbanization continue to encroach upon forests and grasslands, leading to habitat destruction and fragmentation (Lambin & Meyfroidt, 2011). The demand for fuelwood and charcoal remains a significant contributor to deforestation, as many households rely on biomass energy sources due to the lack of affordable alternatives (Ogundele et al., 2016).

The environmental consequences of vegetation loss are extensive in many regions. The expansion of built-up areas at the expense of vegetated landscapes has contributed to the urban heat island effect, decreased air quality, and heightened soil degradation (Richards & Belcher, 2020). Additionally, soil degradation and desertification are other major consequences. The removal of tree cover reduces soil stability, increasing vulnerability to erosion, desertification, and declining soil fertility (Mohammed et al., 2015)

MATERIALS AND METHODS

Study area

Kumbotso Local Government Area (LGA) is one of the forty-four local government areas in Kano State, Nigeria, situated in the central part of the state's senatorial zone. The LGA covers 11 wards: Challawa, Chiranchi, Danbare, Danmaliki, Guringawa, Kumbotso, Kureken Sani, Mariri, Na'ibawa, Panshekara, and Unguwar Rimi. Kumbotso LGA is bordered to the north by Ungogo, Gwale, Kano Municipal, and Tarauni LGAs; to the west by Tofa and Madobi LGAs; to the south by Madobi and Dawakin

Kudu LGAs; and to the east by Nassarawa and Gezawa LGAs.

Geographically, Kumbotso LGA is located between latitudes 11°52' N and 11°58' N of the Equator, and longitudes 8°24' E and 8°37' E of the Greenwich Meridian. The area covers 158 km² and has a population of 294,391, with an annual growth rate of 4.06% and a population density of 2,197.47 inhabitants per km² (NPC, 2006).

The vegetation of the area consists of savannah, characterized by a hot, semi-arid climate. The area features scattered trees across a broad expanse of grassland. It is situated 450 meters above sea level and experiences an average annual precipitation of 850-870 mm, with the majority falling between June and September.(Abaje, 2007; Savannah Journal, 2019)

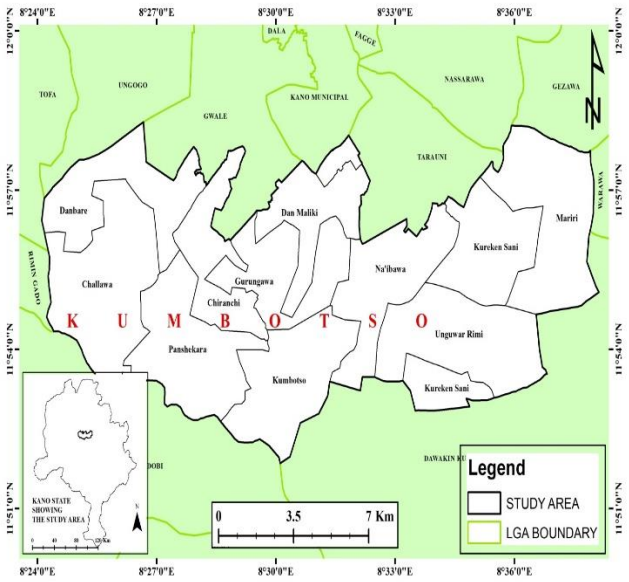


Fig 1:Map of Kumbotso Local Government Area (Source: Geography GIS Lab, Bayero University Kano)

Method of data collection

Satellite images

Landsat Enhanced Thematic Mapper Plus (ETM+) images for the years 2000 and 2012, as well as a Landsat Operational Land Imager (OLI) image for 2024, were obtained from the United States Geological Survey (USGS) EarthExplorer platform (https://earthexplorer.usgs.gov/). Each image has a spatial resolution of 30 × 30 meters and was acquired in October. This period was specifically chosen due to its typically low cloud cover, which coincides with the end of the rainy season when vegetation is still dense and green, making it ideal for vegetation analysis.

The acquired images underwent several preprocessing steps to prepare them for analysis. These processes included layer stacking to combine spectral bands, scan line correction to address data gaps in the 2012 Landsat ETM+ image, and image subsetting to extract the study area.

Sampling techniques

This study adopts a purposive sampling technique to select both the study areas and participants, consistent with approaches recommended for environmental research that incorporates community perspectives (Tongco, 2007). Five wards within the Kumbotso Local Government Area (LGA) that have experienced notable loss of vegetation cover were purposively selected for field investigation.

Participants were also selected purposively, focusing on local community members, based on the following criteria:

1. Individuals who have lived in the community for at least 20 years.
2. Individuals are considered knowledgeable about the environmental history of the area.
3. Community elders with experience in or awareness of land-use practices such as farming, grazing, or land development.

Data were collected through interviews using a well-structured questionnaire.

Data analysis

The subsetted satellite images for the years 2000, 2012, and 2024 were analyzed using a combination of classification and vegetation index techniques. First, the images were classified using the Maximum Likelihood Classification (MLC) algorithm. This supervised classification method categorized the land cover into three distinct classes: built-up areas, dense vegetation, and sparsely vegetated areas. This simplified classification scheme was adopted to highlight changes in vegetation cover over time effectively.

In addition to classification, the Normalized Difference Vegetation Index (NDVI) was calculated for the years 2000 and 2024. To ensure that only areas with vegetation were included in the analysis, a vegetation mask was applied to exclude non-vegetated areas. For each year, regions of interest (ROIs) were created by masking out pixels with NDVI values below 0.2, based on the threshold typically used to define vegetated surfaces (Al-Adoski et al., 2013). These ROIs were then merged using a union operation to include all pixels that had NDVI values greater than 0.2 in at least one of the two years. This step ensured that the analysis focused exclusively on areas that currently have or once had vegetation cover.

To assess spatial variations in vegetation loss, a paired t-test was conducted for each of the 11 wards within the Kumbotso Local Government Area.

To identify the major drivers of vegetation cover loss, six key factors were included in the questionnaire: built-up area expansion, agricultural expansion, fuelwood harvesting, population growth, climate change, and weather variability. Responses to these factors were rated on a Likert scale and analyzed using the Mean Item Score (MIS), calculated as follows:

$$MIS = \frac{\sum X_i}{N}$$

…… Eq (1)

Where:

X_i = is the score given to each factor by the respondent.

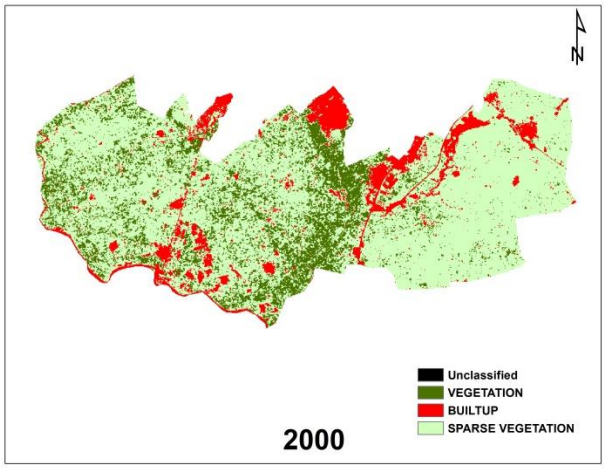
N = is the total number of respondents.

This method provides a quantitative measure of the perceived importance of each factor, allowing for the systematic assessment of their relative contributions to vegetation loss.

RESULT AND DISCUSSION

Land Cover Change Analysis (2000–2024)

The land cover classification revealed substantial changes in vegetation cover in Kumbotso LGA between 2000 and 2024. In 2000, sparsely vegetated areas dominated, covering **70.61%** (111.57 km²), followed by dense vegetation at **18.73%** (29.59 km²), and built-up areas accounting for only **10.66%** (16.84 km²). By 2012, built-up areas had nearly doubled to **20.08%** (31.73 km²), while dense vegetation declined to **13.69%**, and sparse vegetation reduced slightly to **66.23%**. The trend continued into 2024, with dense vegetation drastically reduced to **5.43%** (8.58 km²), built-up areas expanding to **42.62%**, and sparse vegetation further decreasing to **51.95%** (82.08 km²).



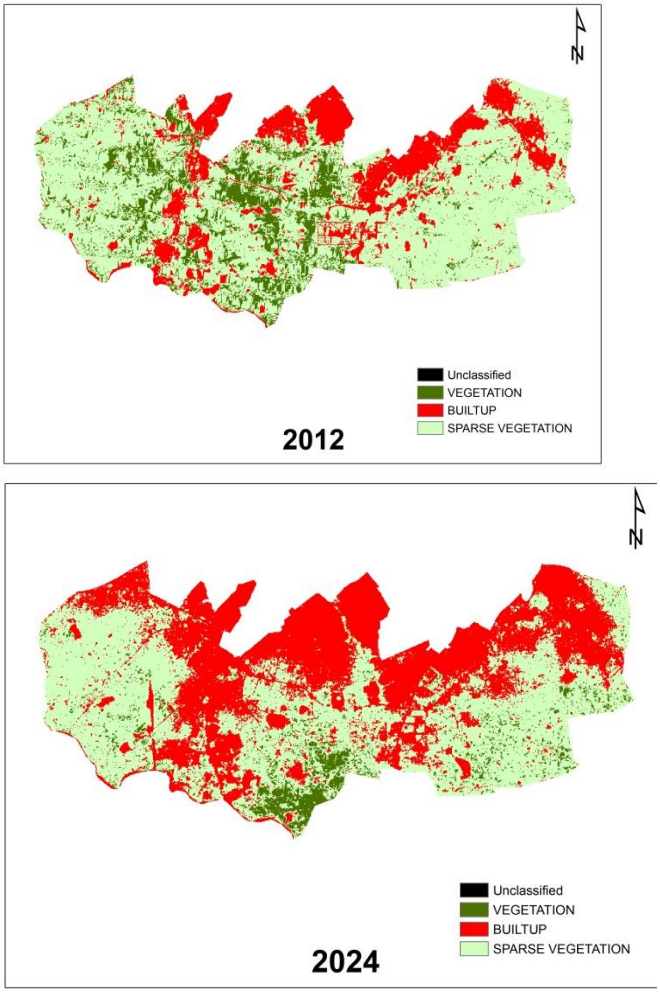


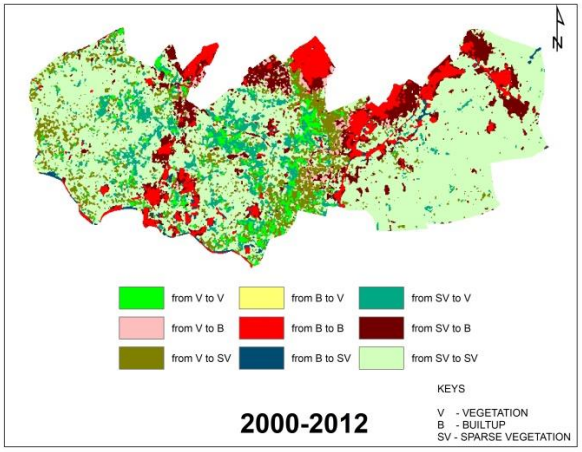
Fig 1: Classified Images of Kumbotso local government area for the years 2000,2012, and 2024 (Source: Geography GIS lab, BUK)

Change Detection Results

Three change detection comparisons were conducted: **2000–2012, 2012–2024,** and **2000–2024:**

1. **2000–2012**:
   From the initial 29.59 km² of vegetation in 2000:
   i. **63.28%** (~16 km²) of the area transitioned into sparse vegetation.
   ii. **10.18%** of the area was converted to built-up areas.
   iii. **11.83%** of sparse vegetation and **3.48%** of built-up areas (0.59 km²) showed minor vegetation gain.
   iv. **13.96%** of sparse vegetation transitioned into built-up areas (15.57 km²).
2. **2012–2024**:
   i. Only **0.19%** (0.06 km²) and **5.62%** (5.88 km²) of sparse vegetation and built-up areas, respectively, were converted to vegetation.
   ii. A significant **24.24%** of vegetation was lost to built-up expansion.
   iii. **63.56%** was converted to sparse vegetation.
   iv. **31.84%** (33.32 km²) of sparse vegetation transitioned into built-up areas.
3. **2000–2024**:
   From the original 29.59 km² of vegetation in 2000, only **10.77%** remained by 2024.
   i. **54.40%** was converted to sparse vegetation.
   ii. **34.82%** transitioned to built-up areas.
   iii. Additionally, **38.31%** (42.64 km²) of the sparse vegetation from 2000 had become built-up areas by 2024.

These results confirm that urban expansion has been the primary driver of vegetation loss over the 24 years.



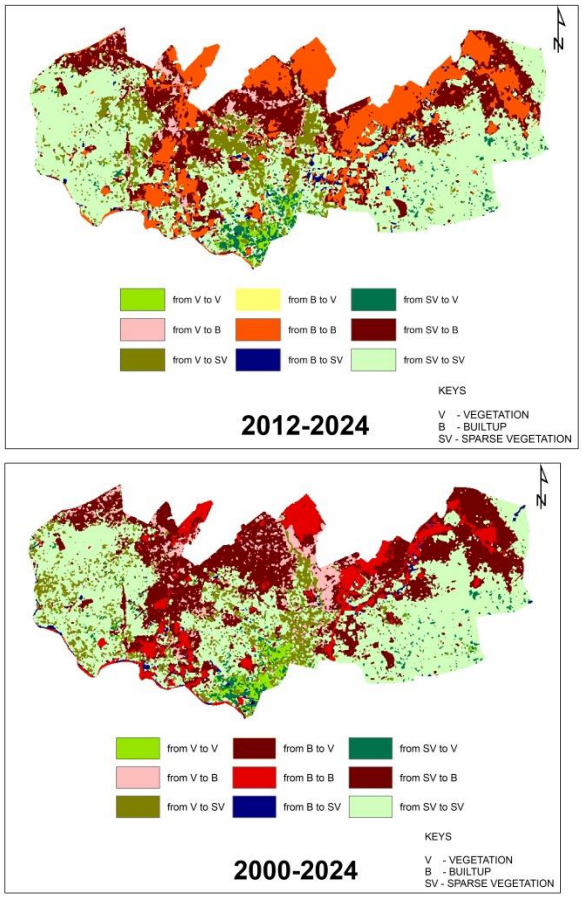


Fig 3: Land use/Land cover trends map of Kumbotso local government area between the years 2000-2012, 2012-2024, and 2000-24 (Source: Geography GIS lab, BUK)

NDVI Statistical Analysis (2000–2024)

To quantitatively assess vegetation change, a paired t-test was performed on NDVI values across 11 wards of Kumbotso LGA. The analysis confirmed a statistically significant reduction in NDVI values in all wards.

Table 1: Ward-wise NDVI value Statistical Analysis (2000–2024)

S/N	Zone	Mean NDVI Difference	t-Stat	Significant?
1	Mariri	-0.0396	73.89	Yes
2	Chiranchi	-0.1349	228.42	Yes
3	Dan Maliki	-0.1705	303.01	Yes
4	Unguwar Rimi	-0.012	34.86	Yes
5	Chalawa	-0.038	170.75	Yes
6	Gurungawa	-0.1055	230.62	Yes
7	Kumbotso	-0.039	128.62	Yes
8	Naibawa	-0.1133	204.18	Yes
9	Danbare	-0.0892	191.87	Yes
10	Panshekara	-0.0715	168.57	Yes
11	Kureken Sani	-0.0404	85.93	Yes

All zones exhibited statistically significant declines in NDVI, indicating a widespread reduction in healthy vegetation across Kumbotso between 2000 and 2024.

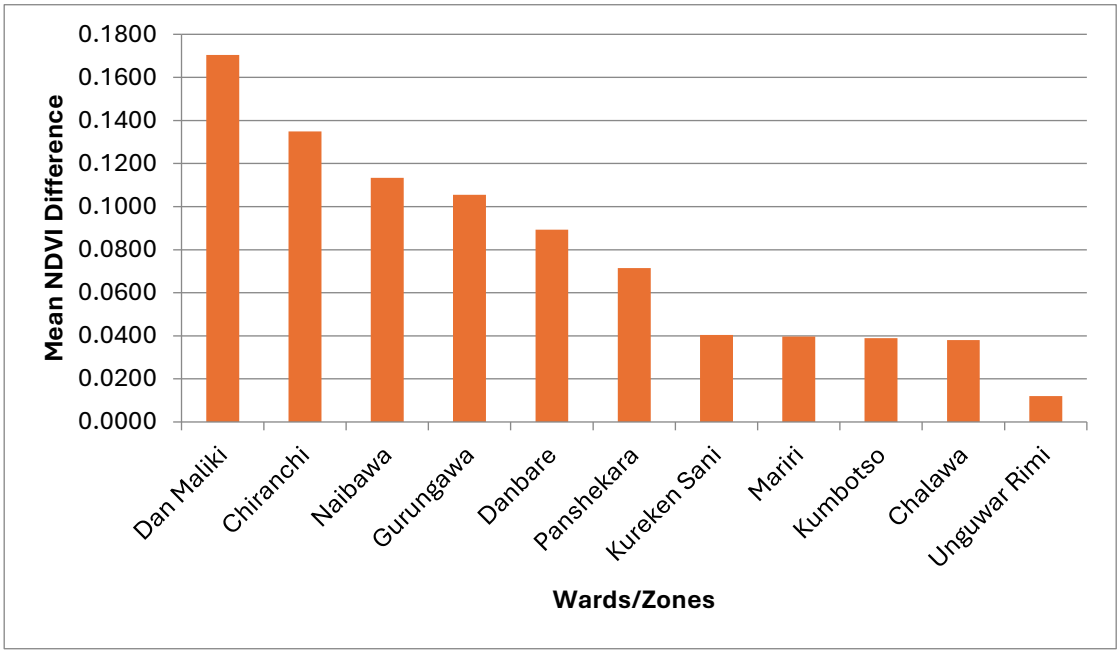


Fig 4: Mean NDVI value difference graph for the wards in Kumbotso local government area from 2000 to 2024

Among the 11 wards, Dan Maliki experienced the highest vegetation loss, followed by Chiranchi and Naibawa. On the other hand, the ward with the least vegetation is Unguwar Rimi. Therefore, the five (5) areas that have the most vegetation cover loss from 2000-2024 in Kumbotso Local Government Area are Danmaliki, Chiranchi, Naibawa, Gurungawa, and Danbare ward.

Perceived Causes of Vegetation Loss

Responses from community interviews were analyzed using the Mean Item Score (MIS) approach to assess the perceived causes of vegetation loss.

Table 2: Factors responsible for the vegetation loss in the Kumbotso Local Government Area MIS table

SN	Factors	MIS	Rank
1	Built-Up Area Expansion	4.86	**1st**
2	Population Growth	4.76	**2nd**
3	Policies/Management Issues	4.14	**3rd**
4	Climate Change	3.36	4th
5	Fuelwood Harvesting	2.42	5th
6	Agricultural Expansion	1.6	6th

The findings reveal that built-up area expansion is perceived as the most significant factor contributing to vegetation loss in Kumbotso. It is closely followed by population growth, which likely exacerbates land

demand and urban expansion. Policy and management issues were ranked third, indicating a perceived deficiency in enforcement or planning. Agricultural expansion was ranked as the least significant factor, possibly due to urban dominance in the study area.

CONCLUSION AND RECOMMENDATIONS

This study has revealed a significant decline in vegetation cover within the Kumbotso Local Government Area between 2000 and 2024. The analysis links this decline to rapid urbanization, population growth, inadequate land-use planning, and unsustainable exploitation of natural resources.

Through the application of Landsat satellite imagery and NDVI analysis, the study identified a substantial reduction in vegetated areas, with only a small fraction of the original green cover remaining by 2024. The most severely impacted wards—Dan Maliki, Chiranchi, Naibawa, Gurungawa, and Danbare—have undergone widespread conversion into built-up areas. These changes have led to adverse environmental consequences, including altered microclimates, reduced water retention capacity, and diminished agricultural productivity.

Community interviews supported the geospatial findings, providing localized perspectives on the drivers and impacts of vegetation loss. Respondents demonstrated awareness of the issue and expressed a willingness to support community-driven initiatives and policy reforms aimed at environmental restoration.

In conclusion, it is recommended that.

1. Authorities should enforce existing land-use regulations and introduce stricter controls on the indiscriminate conversion of land.
2. The government and local stakeholders should implement large-scale tree-planting programs, especially in wards identified as hotspots of vegetation loss.
3. Grassroots environmental initiatives, such as local tree planting and environmental education (awareness), should be encouraged.
4. The regular use of GIS and remote sensing tools should be adopted for vegetation studies, particularly in urban and peri-urban areas.
5. Fuelwood harvesting should be regulated, and the use of alternative, cleaner energy sources should be promoted.

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EVALUATION OF URBAN TREE SPECIES COMPOSITION AND DIVERSITY ALONG SELECTED ROADS IN MAKURDI METROPOLIS, NIGERIA

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ABSTRACT

Understanding the composition of the city's tree population is crucial for developing effective urban forestry practices and environmental management strategies. This study aimed to assess the composition and diversity of urban trees along six major roads in Makurdi, Nigeria, with the goal of informing sustainable urban forestry practices and promoting effective environmental management strategies in the city. Purposive sampling was used to select six major roads in Makurdi based on high traffic jams. Trees with Diameter at Breast Height (DBH) ≥ 10 cm were identified within a 2 km x 2 m belt on both sides of each road. Species composition was determined using a checklist, and abundance was assessed by frequency. Tree diversity was evaluated using the Shannon-Wiener index (H'), species richness (SR), and evenness (E'). A total of 1,763 trees, representing 25 species, were recorded. Tree abundance varied, with Gboko Road having the most (325) and Lafia Road having the least (244). *Delonix regia* was the dominant species (511), followed by *Terminalia mantaly* (281), *Mangifera indica* (230), *Albizia lebbeck* (150), and *Gmelina arborea* (94). Lafia road showed the highest Shannon-Wiener diversity (2.52) and evenness (0.57), indicating a greater species variety and a more balanced distribution compared to Old Otukpo road (2.00 and 0.39, respectively). These findings revealed potential differences in planting strategies and natural regeneration patterns. Understanding these variations can inform sustainable urban forestry practices in Makurdi.

Keywords*: Diversity, Environmental management, Tree Species, traffic-jam, Urban.*

INTRODUCTION

Rapid urbanization poses significant environmental challenges for cities worldwide (Ochola, 2018). These challenges include increased air pollution, the urban heat island effect, and a decline in biodiversity (Bhatti *et al*., 2021). Urban trees play a critical role in mitigating these problems by filtering pollutants, providing shade, and regulating temperature (Zhao and Sander, 2015). A diverse urban forest with a variety of tree species enhances ecological stability and resilience, allowing the ecosystem to adapt to changing environmental conditions (Oehri *et al*., 2017; Dangulla *et al*., 2019).

Makurdi, the capital of Benue State in Nigeria, is experiencing rapid urbanization. While concerns exist regarding the environmental impacts of this growth (Useni *et al*., 2022), updated information on the tree species diversity of urban areas of Makurdi is lacking. Understanding the makeup of the city's tree population is crucial for developing effective urban forestry, sustainable management, and environmental resilience (Agbelade *et al*., 2016). Urban forestry encompasses the planting and management of trees within built

environments, including streets, neighborhoods, and institutional areas (Ezeabasili *et al*., 2015).

This study addresses the knowledge gap by providing updated information on the the tree species diversity of urban areas in Makurdi, Nigeria. Identifying the existing tree species and analyzing their distribution patterns can provide valuable insights for developing sustainable urban forestry practices in the city. Roadside trees, in particular, play a vital role in urban biodiversity conservation and air pollution reduction (Xing and Brimblecombe, 2020). Evaluating these aspects will contribute to improving the overall quality and ecological impact of Makurdi's urban environment.

MATERIALS AND METHODS

The Study Area

The study was conducted in Makurdi, the capital of Benue State, Nigeria. Makurdi has a population of approximately 489,839 people as of early 2025 (Makurdi Population, 2025), a significant increase from the 2006 census figure of 300,377 (NPC, 2006). It represents an annual growth rate of 3.83% over the 19 years, driven by urbanization and migration. It is situated within the Guinea Savanna agro-ecological zone, with coordinates ranging from latitude 7°38'N to 7°50'N, and longitude 8°24'E to 8°38'E of the Greenwich Meridian. The city is situated in the Benue Valley, in the North Central part of Nigeria, and is traversed by the River Benue, the country's second-largest river (Abah, 2013). The relief of the area is generally low-lying, with elevations ranging from below 90 m to 150 m above sea level. There are three main soil types present: alluvial, clayey loam, and sandy. The total land area is approximately 3,993.3 km^2, and it is divided by the River Benue into the North and South Banks (Abah, 2013; Saka *et al*., 2022). Makurdi experiences a tropical climate with alternating wet and dry seasons. The rainy season lasts from April to October, while the dry season lasts from November to March. The town receives consistently high annual rainfall, with an average annual total of 1343.9 mm. The average yearly temperature in the research location varies from 33.8°C (Nigerian Meteorological Agency, 2020).

The vegetation in Makurdi City is predominantly of the the Guinea Savanna type. However, due to human activities, such as the clear-cutting of tree cover, artificial vegetation has replaced natural secondary vegetation in many parts of the town (Abah, 2013). Six (6) major roads in Makurdi City were selected for this study (Figure 1).

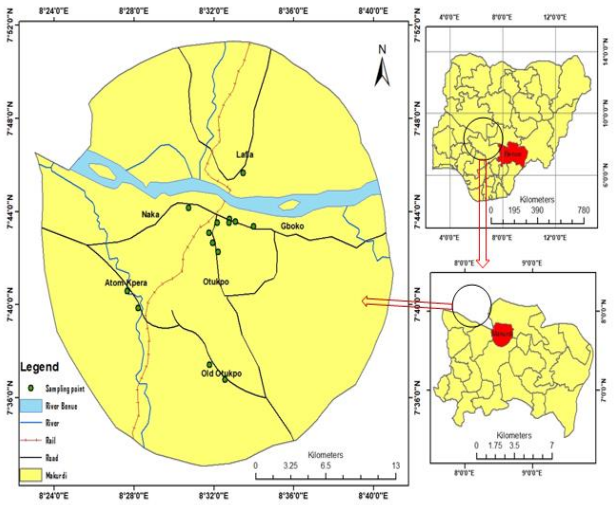

Figure 1: Map of Makurdi city showing sampling points on six (6) major roads.

Sampling procedures

Purposive sampling technique was used to select six (6) major roads in the study area based on a high level of traffic jams, vehicular and human congestion. The selected roads include Gboko Road, Lafia Road, Otukpo Road, Naka Road, Old Otukpo Road, and Atom Kpera Road. On each of the purposively selected roads, tree species within a 2km long and 2m wide strip on both sides of the road were selected and identified for this study to ensure that all roads were covered. In each of the roads, all trees in close proximity to the roads and exposed to traffic, with a diameter at breast height (DBH) of≥10 cm and located above 1.3 m from the ground, were identified for this study (Agbelade and Onyekwelu, 2020).

Data Analysis

Tree species composition

The tree species composition was determined by creating a checklist of species and their corresponding families. The data on the frequency distribution of each

species in the study area were utilized for quantitative analysis (Saka *et al*., 2022).

Tree species diversity

The measurement of tree species diversity involved considering both the number of species present in the sample plots (species richness) and the distribution of abundance among species (evenness of species). To measure the diversity and evenness of woody plant species across the study plots, certain metrics were used: Shannon-Wiener diversity index (H'), species richness (SR), and Shannon's evenness index (E). The calculation of the tree species diversity index followed the methodology outlined in the works of Amonum *et al*. (2019), Meer *et al*. (2018), and Saka *et al*. (2022). By applying this formula, it became possible to determine which tree species exhibit higher levels of diversity within the study area.

i. **Shannon-Weiner diversity index**

Shannon-Wiener index (H') was used to estimate the diversity of the sampled tree species in the study area with equation 6:

$$H' = -\sum[\text{pi ln (pi)}] \ldots\ldots\ldots (1)$$

WhereH' = species diversity index, *Pi* = relative frequency of species, ln = natural logarithm of species proportion (Amonum *et al*., 2019).

ii. **Species evenness index**

The evenness of tree species was assessed by calculating Shannon's equitability (E_H), which was derived from the method described by Agbelade *et al. (*2017):

$$E_H = \frac{H'}{H_{max}} = \frac{-\sum_{i=1}^{S} \text{Pi ln (Pi):}}{\ln(S)} \ldots\ldots\ldots (2)$$

Where H^1 Shannon-Wiener diversity index, Pi = Proportion of S made up of the 1th species, In = Natural logarithm, S =Total number of species in the community

iii. **Species richness**

The analysis of species richness was conducted following the procedure described by Amonum *et al.* (2019):

Species Richness (SR) = $S/\sqrt{N} \ldots\ldots\ldots$ (3)

Where: S = the overall number of species, N = the total number of individuals collected (Amonum *et al.*, 2019)

RESULTS

Composition of Urban Tree Species along Selected Roads

A survey of trees along selected roads in Makurdi, Benue State, Nigeria, identified a total of one thousand seven hundred and sixty-three (1,763) unique species (Table 1). *Delonix regia* emerged as the most abundant species, with a significant presence on Old-Otukpo (117 individuals), Naka (106 individuals), Gboko (92 individuals), and Otukpo roads (76 individuals). Relatively high abundance was also observed for *Mangifera indica* and *Terminalia mantaly* across multiple roads. *Albizia lebbeck* and *Gmelina arborea* were present but less frequent.

Table 1: Composition of Tree Species Identified in the Study Area

		Selected Roads						Total
Family	**Species**	**Gboko**	**Lafia**	**Otukpo**	**Naka**	**Old-otukpo**	**Atom-kpera**	
Anacardiaceae	*Anacardium occidentale*	7	13	3	9	3	5	40
	Mangifera indica	46	51	41	29	28	35	230

Annonaceae	*Polyalthia longifolia*	6	11	16	8	16	13	70
Bignoniaceae	*Newbouldialaevis*	0	3	0	2	0	1	6
Bombacaceae	*Ceiba pentandra*	0	2	1	1	0	1	5
Casuarinaceae	*Casuarina equisitifolia*	3	0	8	6	2	2	21
Combretaceae	*Terminalia catappa*	5	8	21	14	8	18	74
	Terminalia mantaly	50	45	52	47	44	43	281
Euphorbiaceae	*Huracrepitans*	5	2	4	2	2	10	25
Fabaceae	*Albizia lebbeck*	32	16	32	24	15	31	150
	Daniella oliveri	2	0	4	3	0	0	9
	Delonix regia	92	28	76	106	117	92	511
	Parkia biglobosa	9	1	5	2	3	0	20
Lamiaceae	*Gmelina arborea*	35	18	9	8	14	10	94
	Tectona glandis	2	0	0	1	0	2	5
Meliaceae	*Azadirachta indica*	7	12	12	25	9	15	80
	Khaya senegalensis	1	2	0	2	1	0	6
Moraceae	*Ficus benjamina*	6	6	2	6	4	2	26
	Ficus Polita	9	10	9	11	5	4	48
	Ficus thonnigii	0	3	4	3	2	1	13
Moringaceae	*Moringa oleifera*	1	3	1	2	0	2	9
Myrtaceae	*Eucalyptus camaldulensis*	4	5	2	4	1	3	19
	Eucalyptus globules	0	1	1	0	1	0	3
	Psidium guajava	1	2	0	2	1	2	8
Rutaceae	*Citrus sinensis*	2	2	1	3	0	2	10
	Grand Total	325	244	304	320	276	294	1763

Diversity and Distribution of Tree Species along Selected Roads

A survey of trees along selected roads in Makurdi, Benue State, Nigeria, revealed a total of 1,763 individuals (Table 2). Gboko Road had the highest number of trees (325), followed by Naka Road (320 trees), Otukpo Road (304 trees), Atom-Kpera Road (294 trees), and Lafia Road (244 trees). Species diversity varied across roads. Lafia road had the highest Shannon-Weiner diversity index (2.52), indicating the greatest variety of tree species. Conversely, Old Otukpo road had the lowest index (2.00), suggesting a limited range of species. Evenness indices followed a similar pattern, with Lafia Road having the highest value (0.57) and Old Otukpo Road having the lowest value (0.39).

Beta diversity analysis (Table 3) revealed weak connections between the tree communities along

different roads. The highest dissimilarity (beta diversity = 0.16) was observed between Lafia and Gboko roads, while Lafia and Naka roads showed the lowest dissimilarity (beta diversity = 0.09). It suggests significant variation in species composition among most roads.

Table 2: Tree Species Diversity and Distribution along Different Roads in Makurdi

	Selected Roads					
Diversity indices	**Lafia**	**Gboko**	**Otukpo**	**Naka**	**Old-otukpo**	**Atom-kpera**
Individuals	244	325	304	320	276	294
Species no.	22	21	21	24	19	21
Dominance_D	0.11	0.15	0.13	0.16	0.23	0.16
Shannon_H	2.52	2.28	2.35	2.36	2.00	2.26
Evenness_e^H/S	0.57	0.46	0.50	0.44	0.39	0.46

Table 3: Beta-Diversity of Urban Tree Species along Selected Roads in Makurdi

Roads	**Lafia**	**Gboko**	**Otukpo**	**Naka**	**Old-otukpo**	**Atom-kpera**
Lafia	-					
Gboko	0.16	-				
Otukpo	0.12	0.14	-			
Naka	0.09	0.07	0.11	-		
Old-Otukpo	0.12	0.15	0.15	0.16	-	
Atom-Kpera	0.12	0.14	0.14	0.07	0.20	-

DISCUSSION

Composition of Urban Tree Species along Selected Roads

The dominance of Delonix regia along the selected roads in Makurdi is a notable finding, reflecting a pattern frequently observed in tropical urban environments. This dominance can be attributed to both environmental suitability and historical planting preferences, as highlighted by Jim and Chen (2021) in their study on aesthetic preferences for urban trees in Hong Kong. Their research highlights how historical and cultural factors influence urban tree composition, often resulting in the prevalence of visually appealing species. Furthermore, Olagunju *et al.* (2022), in their study of urban tree diversity in Lagos, Nigeria, also found that human selection plays a significant role in determining which trees populate urban areas. This study collectively shows that while dominant species like Delonix regia contribute to urban aesthetics, they may also reduce overall biodiversity and ecosystem resilience. The presence of economically valuable

trees such as *Terminalia mantaly, Albizia lebbeck*, and *Gmelina arborea* underscores the complex interplay between ecological and socio-economic factors in urban forestry. As demonstrated by Egbeyale *et al.* (2023) in Ibadan, Nigeria, these species often provide essential resources for local communities, underscoring the need for sustainable management practices. The research by Mutuku and Kioko (2020), conducted in Nairobi, Kenya, also reinforces the importance of protecting trees of socio-economic value. The prevalence of Fabaceae and Moraceae families, consistent with the findings of Mustapha et al. (2022) in Jigawa State, reinforces the need to consider regional plant distribution patterns. The study also aligns with previous findings by Agbelade *et al*. (2017), who reported Fabaceae and Moraceae as dominant families in Abuja, Nigeria. Understanding these patterns and the impact of anthropogenic selection, as highlighted by Stewart *et al.* (2021) in the UK, is crucial for effective urban forestry planning. This regional pattern helps to predict future urban forest composition.

Diversity and Distribution of Tree Species along Selected Roads

The moderate tree species diversity observed in this study, as indicated by the Shannon-Wiener index, aligns with findings from other developing urban areas in Nigeria (Salami and Akinyele, 2017) and across Africa (Mbow *et al*., 2019). However, it is lower compared to meticulously planned urban forests in developed countries, as evidenced by Nowak *et al.* (2020) research on urban tree cover in the USA. Recent studies emphasize the importance of enhancing urban tree diversity to maximize ecosystem services and climate change resilience. For instance, Oke *et al.'s* (2023) research on urban heat island mitigation in Toronto, Canada, demonstrates that diverse tree canopies provide more effective cooling than monocultures. The uneven species distribution and weak beta diversity observed in this study highlight the challenges of maintaining ecological connectivity in fragmented urban landscapes. Studies on urban ecological corridors, such as the global review by Fahrig *et al.* (2019), emphasize the importance of spatial planning and management to promote species dispersal and gene flow.

Furthermore, research employing spatial analysis and remote sensing techniques, as seen in the Turner *et al.* (2021) study in Australia, provides valuable insights into the factors influencing tree distribution and connectivity. Therefore, urban forestry planning in Makurdi should incorporate strategies that enhance tree species diversity, promote connectivity, and maximize the provision of ecosystem services. This study provides a valuable baseline for understanding the current state of tree diversity and distribution in Makurdi. Future research should focus on exploring the factors influencing these patterns, specifically by conducting soil nutrient analyses, microclimate assessments, and surveys of local residents' planting preferences, to provide a more holistic understanding of urban tree distribution. Long-term monitoring of planted trees will also be essential to track the success of urban forestry initiatives.

CONCLUSION AND RECOMMENDATIONS

This study examined urban tree composition and diversity along selected roads in Makurdi, Nigeria. A total of 1,763 trees were identified, with *Delonix regia* as the dominant species. Gboko road recorded the highest tree abundance, while Lafia road had the lowest. Diversity indices varied across roads, with Lafia Road exhibiting the highest Shannon-Wiener index (2.52) and Old Otukpo Road the lowest evenness index (0.39). Beta diversity analysis indicated low similarity in tree composition between roads.

These findings highlight variations in natural regeneration patterns, planting and management strategies, and environmental conditions across Makurdi. To improve urban forest sustainability, further research into these factors is recommended. Diversifying tree species selection and protecting existing highly diverse populations, particularly along roads with greater species variety, should be prioritized in urban forestry planning. Integrating species with high carbon storage potential can also contribute to climate change mitigation efforts.

Community involvement is crucial for the sustainability of urban forestry. Initiatives such as participatory tree-planting programs and partnerships with environmental institutions can promote environmental stewardship and support its implementation. By promoting a more diverse and ecologically balanced urban forest, Makurdi can ensure the long-term environmental and social benefits that trees provide.

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SUBTHEME 5: INNOVATIVE UTILISATION OF WOOD AND FOREST PRODUCTS FOR SUSTAINABLE DEVELOPMENT

CHARACTERIZATION OF LIGNOCELLULOSIC SAWDUST (LCS) FOR ENHANCED SUITABILITY IN WASTE-TO-ENERGY APPLICATIONS THROUGH BIOLOGICAL PRETREATMENT

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Abstract

This study investigates the potential of biological pretreatment using *Pleurotus ostreatus* to enhance the suitability of lignocellulosic sawdust (LCS) from *Gmelina arborea* for waste-to-energy applications. The untreated and treated LCS were analysed for total solids (TS), volatile solids (VS), and the contents of lignin, cellulose, and hemicellulose. Results showed a reduction in TS (from 94.21% to 90.68%) and VS (from 72.00% to 68.45%) after fungal treatment, indicating degradation of organic matter. The lignin content decreased significantly, while the cellulose and hemicellulose contents improved, suggesting an enhanced substrate quality. These findings demonstrate the efficacy of biological pretreatment with *P. ostreatus* in enhancing the biodegradability and energy potential of lignocellulosic sawdust (LCS), providing a sustainable and eco-friendly strategy for biomass valorisation and laying the foundation for optimising bioenergy production from lignocellulosic waste.

Keywords: lignocellulosic biomass; sawdust; biological pretreatment; waste-to-energy

Introduction

The increasing demand for alternative energy sources, driven by the energy crisis and fuel tension, has led to the exploration of biomass, such as sawdust, as a potential solution. Sawdust, a lignocellulosic wood residue composed of cellulose, hemicelluloses, and lignin, has traditionally been classified as waste due to its abundance and environmental impact. However, recent research has shown that lignocellulosic sawdust (LCSs) can be effectively utilized for biofuel and other chemical products, as well as for value-added products, making it a promising biomass material for waste-to-energy applications. (Adegoke *et al.,* 2014; Adegoke and Ayodele, 2015; Chen *et al.,* 2017; Baruah *et al.,* 2018; Adegoke *et al.,* 2019; Adegoke *et al.,* 2020) However, one of the challenges in utilizing sawdust for energy production is its high lignin content, which makes it resistant to biological degradation and decreases its biogas production potential (Olatunji *et al.,* 2021; Banu *et al.,* 2021).

To address this challenge, biological pretreatment methods, such as fungal pretreatment using *Pleurotus ostreatus,* have been investigated (Muhammad *et al.,* 2019; Banu *et al.,* 2021; Aleksandar *et al.,* 2023). This pretreatment process effectively reduces the lignin content of sawdust through enzymatic degradation, leading to the release of bound cellulose and hemicellulose, which can then be more readily converted into biogas (Kumar and Sharma, 2017; Muhammad *et al.,* 2019; Olatunji *et al.,* 2021; Chhetri, *et al.,* 2022) This

approach offers a sustainable and environmentally friendly method for enhancing the energy potential of lignocellulosic biomass without the need for harsh chemicals or high energy inputs (Kumar *et al.,* 2021; Sharma *et al.,* 2023).

This study, therefore, presents novel insights into the efficacy of *Pleurotus ostreatus* fungal pretreatment for enhancing the suitability of LCSs for waste-to-energy applications. By characterising the physicochemical properties of LCSs and assessing the impact of fungal pretreatment, this study sheds light on a sustainable approach to improve the energy potential of biomass materials, contributing to the development of renewable and environmentally friendly solutions.

Materials and Methods

Raw materials

Homogeneous lignocellulosic sawdust (LCS) of *Gmelina arborea* was sourced from the sawmill section of the Department of Forest Products Development and Utilization (FPD&U), Forestry Research Institute of Nigeria. The LCS was initially air-dried and then sieved into a particle size of coarse (1 mm - 700 μm), following the methods outlined by Joshua et al. (2016). Subsequently, it underwent further air-drying at ambient temperature before being used in the experiment. All chemicals used were of analytical grade.

Biological pretreatment of lignocellulosic sawdust (LCS)

Following the method described by Aleksandar *et al. (2023), a fresh LCS was mixed with boiling water at a 1:1 mass ratio*. After the temperature of the wet LCS decreased below 30 °C, wheat bran and $CaCO_3$ were added to the LCS at a ratio of 10:1:1. The mixture was then inoculated with mycelium of *Pleurotus ostreatus*, placed in polythene bags, and kept in darkness for 30 days. On day 30, small holes were cut in polythene bags to allow fruiting bodies to form outside the sacks. A luminescent light and an air humidifier were switched on in the room for the next 3 months. The pretreated LCS was stored in a refrigerator at 4 °C.

Physicochemical characterization of LCS

The physicochemical parameters were determined according to the National Renewable Energy Laboratory (NREL) Laboratory Analytical Procedure and the American Society for Testing and Materials (ASTM) Standards. The methods used to determine various parameters are shown in Table 1.

Table 1. Methods for determining selected physicochemical parameters

Parameters	Standards
Moisture Content	NREL
Total & Volatile Solid	NREL; ASTM E1756-08
Cellulose	ASTM E1721-01
Lignin	ASTM D1106-21

Results and Discussion

Fungal-pretreatment of LCS

The use of *Pleurotus ostreatus* for the fungal pretreatment of LCS has been successfully demonstrated. This fungal species effectively colonises LCS, resulting in a reduction in its lignin content. This reduction is attributed to the enzymatic activity of *P. ostreatus*, which produces various enzymes capable of degrading lignocellulosic biomass. These enzymes, such as phenoloxidase, laccase, lignin peroxidase (LiP), and manganese peroxidase (MnP), play crucial roles in lignin degradation (Suryadi *et al.,* 2022; Kumar *et al,* 2015). They interact with lignin through oxidative reactions, targeting its complex structure and breaking it down into smaller, more digestible fragments. This enzymatic action modifies the lignin structure, increasing its susceptibility to further degradation by other microorganisms or enzymes. This process enhances the digestibility of LCS, leading to improved conversion

efficiency in waste-to-energy applications. Moreover, *P. ostreatus* enzymatic pretreatment is a sustainable and environmentally friendly approach that utilizes natural processes to enhance the energy potential of lignocellulosic biomass without harsh chemicals or high energy inputs (Song *et al.,* 2014; Kumar *et al.,* 2021; Xiaolin *et al.,* 2022;)

Physicochemical Analyses

Moisture Content

The average moisture content of the coarse LCS was 8.12 %. The moisture content plays a crucial role in determining the total energy required for biomass disintegration during energy utilization and can also affect the internal temperature within the biomass (FR, 2024). The observed differences in moisture content among LCS particles of different sizes could be attributed to variations in surface area. Higher moisture content can create more favourable conditions for microbial growth, including fungi, which could impact the composition and stability of the biomass (Chitra *et al.,* 2018).

Effect of *Pleurotus ostreatus* Treatment on Total and Volatile Solids of Coarse LCS

The assessment of the dry matter contents, specifically the total solids (TS), of LCS treated with *P. ostreatus* revealed a slight reduction from 94.21 % in the untreated LCS to 90.68 % in the treated LCS (Figure 1). This reduction is indicative of the partial degradation of organic components, likely due to the enzymatic action of ligninolytic fungi such as *P. ostreatus*. TS consist of both digestible and non-digestible fractions (Leong *et al.,* 2019), and their reduction after treatment suggests metabolic consumption and conversion of these materials into fungal biomass and gaseous byproducts. Comparable values have been reported by scholars; for instance, oak sawdust was found to have a total solid content of 92.21% (Ali *et al.,* 2019), supporting the range observed in this study. The relatively high total solid content in the coarse particle size used may be attributed to its larger surface area, which enhances microbial colonization and moisture retention. Furthermore, higher dry matter content is often correlated with greater nutrient density, which can support more efficient microbial activity during anaerobic digestion and potentially enhance biogas yield (Orhorhoro *et al.,* 2017d).

In terms of volatile solids (VS), which represent the biodegradable portion of the total solids, a reduction was also observed, from 72.00% in the untreated LCS to 68.45% following fungal treatment (Figure 1). This decline reflects the metabolic utilisation of organic matter by P. ostreatus, particularly components such as cellulose and hemicellulose, as well as partial lignin degradation. Scholars have reported even higher volatile solid contents in sawdust, such as 94.3 % documented by Okewale *et al.* (2018), indicating variability depending on wood type, particle size, and pretreatment conditions. Volatile solids are crucial in determining the anaerobic digestion potential of a substrate, as they represent the fraction that can be converted to biogas under optimal conditions (Boadu *et al.,* 2023). A higher VS content typically correlates with greater biogas yield potential, as these organic constituents serve as the primary feedstock for microbial conversion during anaerobic fermentation (Oyiboruona *et al.,* 2023). Despite the reduction in VS following treatment, the improved biodegradability and structural modification of the substrate due to fungal action suggest enhanced substrate accessibility and digestibility, potentially improving overall process efficiency in downstream applications such as biogas production.

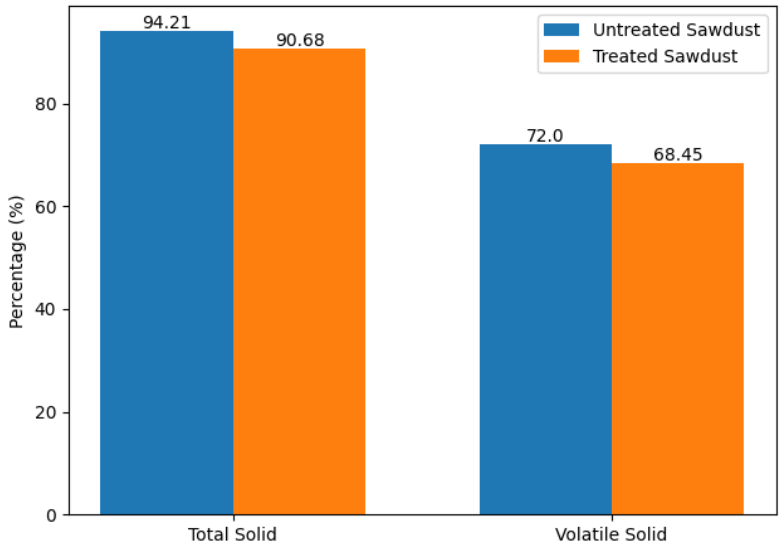

Figure 1: Effect of biological pretreatment with *Pleurotus ostreatus* on TS and VS of coarse LCS.

Structural Composition of Coarse LCS

The structural composition analysis of coarse LCS, both untreated LCS and treated LCS, provided crucial insights into the effectiveness of biological pretreatment using *P. ostreatus*. The study revealed a marked reduction in lignin content (wt%) from 29.20% in UC to 20.10% in TC (Figure 2). It indicates the delignification potential of *P. ostreatus*, which plays a significant role in improving the biodegradability of lignocellulosic biomass. The reduction in lignin content can be attributed to the action of ligninolytic enzymes, such as laccase and manganese peroxidase, produced by the fungus, as supported by Wan and Li (2012), Nadir et al. (2019), and Kainthola et al. (2021).

In parallel, cellulose content (wt%) showed a significant increase from 45.54 % in untreated LCS to 56.40 % in treated LCS (Figure 2). This increase suggests that as lignin is selectively degraded, cellulose becomes more bioavailable for microbial or enzymatic attack. The removal of lignin disrupts the rigid matrix that encases cellulose fibres, facilitating better access by hydrolytic agents. These findings reinforce the assertion by Elisashvili *et al.* (2008) that white-rot fungi degrade lignin more effectively than hemicellulose, thereby improving cellulose exposure. Studies on biological pretreatment offer a promising approach to lignin degradation with minimal impact on cellulose, thereby conserving valuable fermentable sugars (Anita *et al.,* 2016).

Moreover, the hemicellulose content (wt%) dropped from 25.56% in untreated LCS to 23.60% in treated LCS (Figure 2), further supporting the efficiency of fungal pretreatment in modifying the lignocellulosic structure. While hemicellulose is more readily degradable than lignin, its reduction is often secondary to lignin breakdown. The observed trend in hemicellulose supports the selective degradation capability of *P. ostreatus*. However, the effectiveness of pretreatment in this study suggests that *P. ostreatus* was able to infiltrate and act on the dense matrix of coarse sawdust.

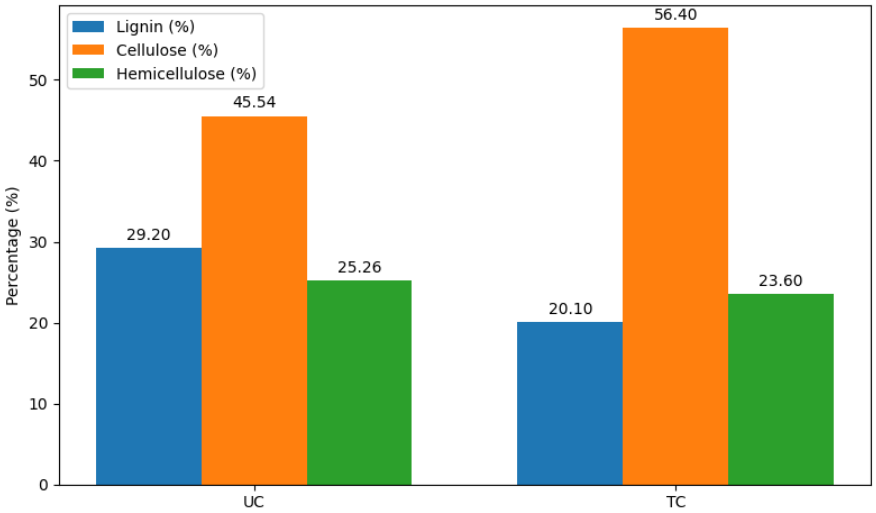

Figure 2: Effect of *Pleurotus ostreatus* treatment on the lignocellulosic composition of coarse LCS

Conclusion

This study presents important findings on the use of Pleurotus ostreatus fungal pretreatment to enhance the suitability of lignocellulosic sawdust (LCS) for waste-to-energy applications. Physicochemical analyses revealed significant changes in dry matter, volatile solids, cellulose, hemicellulose and lignin content, highlighting the effectiveness of the fungal treatment in reducing lignin and enhancing digestibility. These improvements suggest a promising approach to increasing the efficiency of biomass conversion for bioenergy production.

The findings contribute to sustainable biomass utilization by deepening the understanding of fungal pretreatment mechanisms and their effects on LCS properties. This knowledge lays a strong foundation for further research and practical applications in both bioenergy generation and waste management, benefiting academia and industry alike.

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Theme: *Forest Sustainability in the face of climate change and insecurity: Innovative technologies and Strategies*

TREE RING MEASUREMENT METHODS AND THEIR RELIABILITY FOR ASSESSING TREE AGE AND GROWTH CONDITIONS

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Abstract

Trees are intrinsically linked to their environment, and their growth is affected by a variety of natural and artificial processes and events that are consistently and reliably recorded in the rings of the trees. Tree ring width variation is the most common ring parameter studied in terms of tree age, growth, and climate relationships. Although there are recent reports of using late-wood density and wood chemical composition. Disc cutting is a common destructive method that involves felling trees to remove discs of 2-5 cm thickness from proportionate positions along the merchantable length of the stem. It is described as laborious, wasteful, and generally considered unsustainable, and is highly discouraged. Meanwhile, the improved methods utilise advanced technologies, such as x-ray beams and advanced computer software. They include: X-ray densitometry, which creates a density profile within each growth ring, and then there is computed tomography X-ray, which produces a 3-dimensional image of the rings from the core sample. Image analysis software like LINTAB, Win DENDRO, and some of their disadvantages were also discussed, and more advanced substitutes, such as Pixel-Contrast Densitometry, have been suggested. The reliability of these methods in maintaining large-scale environmental records spanning millennia, as well as the use of precise sample collection and measurement techniques, was discussed. Variation in growth conditionss and technological limitations are some of the challenges associated with these methods of tree ring width measurement. We recommend increasing tree age-climate relation studies in Nigeria and utilising innovative non-destructive methods, given the current status of forest cover in Nigeria.

Keyword: Xylogenesis, Ring width, X-ray densitometry, Earlywood, Maximum latewood density

Introduction

A tree is a biological material with growth as one of its fundamental characteristics. The appearance of thick, dual coloured concentric lines on the transverse section of the tree stem represents what seems to be one of the most influential features of the tree – growth rings. It is described as a layer of xylem cells formed during a year of the the growing season. Tree rings have been widely used for studies relating to tree age determination and growth trend assessment (Wilmking *et al.,* 2020; Ricker *et al.,* 2020; Anderson-Teixeira *et al.,* 2022). One of the prominent ring parameterss studied is the ring width variation, which is a function of the interchange of conduciveness of weather conditions during the the growing season. Usually, at the beginning of growing season when there is enough moisture (in the tropic) or adequate temperature (in the temperate), the trees produces less dense xylem cells with wide pores. Still, towards the end when resources become limited and competition persists, the trees produce dense cells with thicker walls (Pandey, 2021). Other important tree ring parameters include latewood density, chemical composition, and stable isotopes (Xu *et al.,* 2024). In addition to tree age determination, tree

rings keep long term records of environmental and climate condition spanning decades and millennia which are used as the basis to study the interaction between climate variation and tree age/size growth (Quesada-Román *et al.,* 2022), and, to understand the pattern of global changes caused as a result of natural and anthropogenic influences which affect the forest growth and productivity (Walker *et al.,* 2021). Achieving these information is possible through ring measurement and tests using different methods with various precision and procedures.

There are different methods of tree ring measurement, what may look simply as the act count counting circular line across the stem cross section may equally be a key to exploring the interrelationship between trees and the environment, reconstruction of past climate records as well as predicting the possible global change scenarios to plan for its mitigation. The conventional tree ring width measurement method involves manual assessment of the ring width using simple equipment, such as a metre rule or counting individual rings from a disc cut from the stem. This method is characterised as destructive, inefficient, laborious, and errors can easily be made (Gao *et al.,* 2017). Some of the advancedd methods, among others, include computed tomography (X-ray) methods (Putra, 2019), image processing software designed with ring detection abilities (Divya and Kaur, 2021), micrographic imageries, and micro-destructive needle measuring methods (Hu *et al.,* 2020).

The reliability of tree ring width measuring methods is closely tied to the acceptance of tree rings as environmental proxies in maintaining a useful environmental record for assessing tree growth and climate relationships, as well as their application in global change studies (Frank e*t al.,* 2022). It is evident from the continent-wide spread of tree ring research and the establishment of tree ring data collection centres/laboratories, such as the International Tree Ring Data Bank (ITRDB) and the National Centres for Environmental Information (NCEI). The visibility of the rings on a wood sample affects its reliability, sometimes due to insufficient visibility of the early wood-late wood boundary, which can result in errors, especially in counting, leading to incorrect result presentation (Lukashik *et al.,* 2021). It is usually common in the manual ring measurement method. The size of the tree or its age can also affect the reliability of the measuring process; trees are heterogeneous, and some may have more complex growth patterns that can only be assessed by more advanced methods (Orozco-Aguilar *et al.,* 2018). This write-up gives an overview of some of the advanced methods of tree ring width measurement and the advantages they have over the conventional methods.

Biological Basis for Tree Ring Formation

Tree rings are the end product of the cell transformation process called xylogenesis. This process involves the production and transformation of cambial cells into wood after passing through different stages. Xylogenesis is controlled internally by the plant hormone (Buttò *et al.,* 2020), and externally by the availability of limiting factors – a limiting factor is any environmental factor that can significantly affect the growth of an organism in an ecosystem (Stine, 2019). In the case of tree ring formation, the limiting factors are precipitation in tropical regions and temperature and day length in temperate or high-altitude areas. Studies have grouped the process of wood formation into five stages: cell division – mother cambial cell splits to produce two daughter cells; the newly formed xylem cells enlarged; building of secondary cell wall by the deposition of cellulose and hemicellulos; lignin impregnation into the cell wall and lastly apoptosis or programmed cell date leading to formation of fully formed wood (Rathgeber *et al.,* 2016). At the beginning of the growing season, when the limiting factors are sufficiently available, the trees initiate xylogenesis, following the mentioned stages, to produce wood. Wood produced at this phase are called the early wood are characterised with wider lumen and narrow cell walls, but as the growing season is running out. The competition for the declining moisture – especially for the trees growing in the tropical region –the xylogenesis process slows down, resulting in the production late wood, which has thicker walls and narrow lumen. The differences in the microscopic features of early wood and

late wood help to differentiate the two phases of the the annual growth period. This distinction is more visible in trees growing in the temperate regions, where there is a sharp contrast between the period of active cambial activities and the period of dormancy. However, this is not the case for most tropical tree species, as it is difficult to detect due to the distribution of their cellular structure (Quesada-Román *et al.,* 2022).

Ecological Factors Affecting Tree Ring Formation

Rainfall is considered a common growth factor for trees in the tropical region. It significantly influences many processes in tree physiology; it affects nutrient synthesis and transportation, provides turgor for secondary xylem cell differentiation during xylogenesis, and controls the activation and dormancy of the cambial cells in the tree. Usually, in abundance, rainfall increases the rate of early wood production, mostly at the beginning of the growing season. During the dry season, the trees adapt by slowing down cambial activity, leading to late wood production. Studies have reported a correlation between tree ring formation and rainfall, and the findings indicate that the specific effect of rainfall varies according to the local climate conditions of an area (Areola and Fasona, 2018; Pumijumnong *et al.,* 2023). The timing, intensity, and distribution in the tropical rainforest are significantly different from those in much drier regions, such as arid and Sahel environments. In some areas, increased rainfall may lead to higher rates of wood formation, while in others, it may have little effect or even be detrimental to tree growth. Extreme events, such as extreme rainfall, droughts and floods, can significantly impact tree growth and wood formation in tropical regions (O'Donnell *et al.,* 2021).

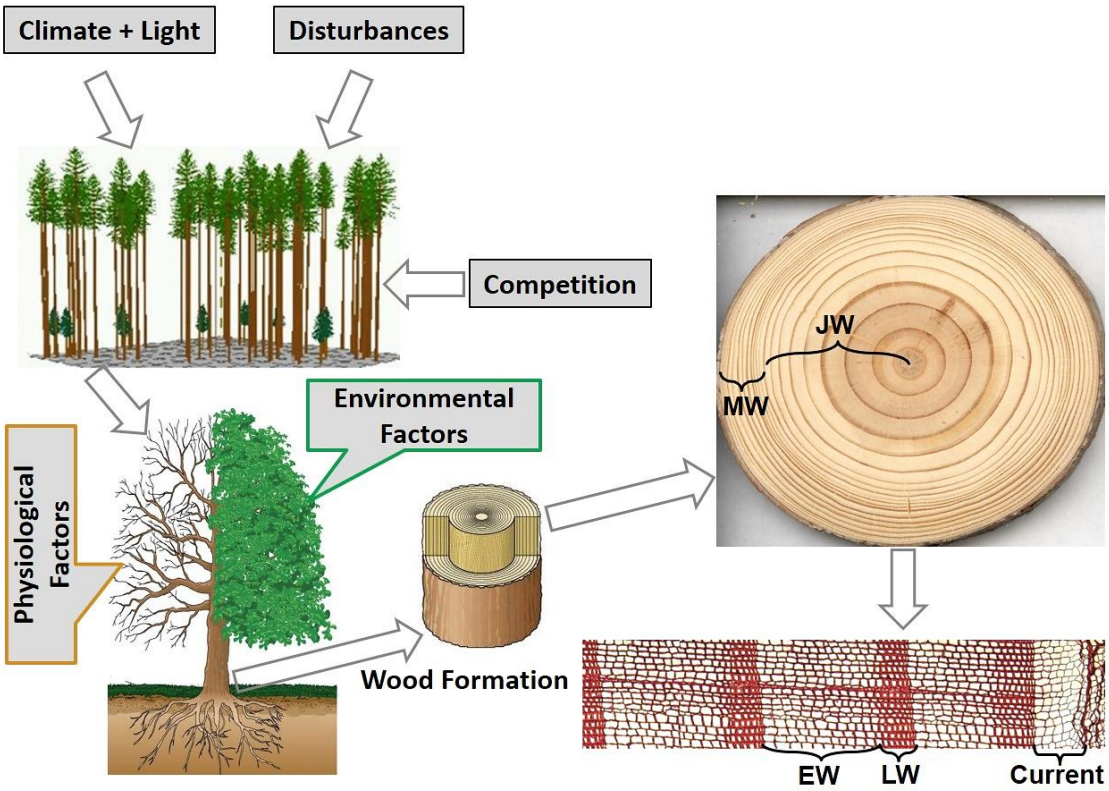

Figure 1: Schematic diagram of ecological factors influencing wood formation, EW and LW early wood and latewood (Zhang *et al.,* 2020).

Traditional Method of Ring Width Measurement

There are two ways samples are collected in wood studies: destructive and non-destructive methods. The most common and conventional destructive method is the disc cutting method. It involves cutting a disc of 2–5 cm thickness (Figure 2) from a prescribed position, such as at the base, middle, or top, or at a proportional distance along the merchantable height of the tree. In most cases, a transparent plastic meter rule was used to measure the distance between two rings on the disc's cross-section. Some of the advantages of this method include giving a more precise and clear display of the growth ring for accurate measurement across the transverse section of the disc, and providing access to more data generation than core samples. The disc cutting method has been reported in a number of studies examining the relationship between tree growth climate and other wood properties (Sousa *et al.,* 2012; Riki *et al.,* 2019; Bon *et al.,* 2020). However, the significant problem with this method is its destructive nature; it involves felling or cutting a substantial portion of the standing tree. The method is regarded as unsustainable, and its unmonitored application method has been discouraged, especially when measuring the ring width of tree species with high cultural and economic importance (Hu *et al.,* 2020).

Figure 2: wood disc sample for ring width measurement (Oyelere *et al.,* 2019)

Advanced Methods of Tree Ring Width Measurement

As a result of advancements in technology and the expansion of tree ring analysis applications, improved methods have been introduced to counter some of the disadvantages of destructive methods. Most of the innovative methods are based on the following:

X-ray Densitometry method – this method was designeded to utilise density, one of the most influential properties recognised in the context of wood properties analysis. The method involves measuring the variation in wood density, specifically the maximum latewood density (MXD) within the growth rings of trees (Lindeberg, 2004). The basic principle of this method is that once the sample core is exposed to the densitometry, it releases an x-ray beam through the core sample, which absorbs the x-ray. The amount of x-ray absorbed by each ring will then be quantified, and a density profile will be based on the cellular characteristics of the two distinct wood types within the ring. The late-wood portion of the ring absorbs more x-ray, given its high density, while the early-wood portion absorbs less and appears lighter on the x-ray image produced. One significant

advantage of this method, in addition to its accuracy and reliability, is its clear demarcation of ring boundaries, which makes it more valuable in understanding the growth patterns in trees and in the development of tree ring chronology in dendrochronology (Gaitan-Alvarez *et al.,* 2019; Xu *et al.,* 2024). Some of the challenges of x-ray densitometry often stem from variations in density data collection across different laboratories that employ different techniques, which in turn affect accuracy, especially during the compilation of spatially wide-scale data (Björklund *et al.,* 2019).

Computed tomography X-ray method – This method involves producing images from core samples using a three-dimensional X-ray scan to extract the wood density profile. The scanner initially creates a two-dimensional image of the core samples, which will later be reconstructed into a three-dimensional model. The method was developed by Van den Bulcke *et al.* (2014) and has been increasingly applied in tree ring width measurement because it produces accurate results by automatically edge out boundaries by differentiating denser latewood from less dense earlywood (Martinez-Garcia et al., 2021) and adjusting the image according to grain angle. In addition to tree ring width measurement, the method is also used for density measurement, although samples need to be dried (Vannoppen *et al.,* 2017). However, the complex internal structure of a tree and the variation in ring width distribution patterns make it a bit challenging to recognise the tree rings, which in a way affects the accuracy of the method (Hu *et al.,* 2020). The method is also not compatible with outdoor applications and it can potentially expose the operator to radioactive danger (Van Den Bulcke *et al.,* 2019).

Image Analysis Software – converts tree rings to digital images for width measurements. It involves the use of digital cameras and various computer software, and a feature detection algorithm to detect ring boundaries from core samples and wood disks. The application of image analysis software has been introduced for a long time, ever since the discovery of the damaging nature of destructive methods. Since its introduction, various image analysers have been used, such as the LA-S plant image analysers, LINTAB tree ring analyser, and WinDENDRO tree ring measurement. The use of image analysers has been employed in tree growth assessment and application in global change studies, such as dendrochronology, to examine past forest disturbances, forest fires, and insect attacks, and has proven to be reputable in terms of accuracy and precision. Digital cameras are preferred over scanners for image acquisition because they are more flexible, can be used on more sensitive samples, such as decayed or burnt wood, and are more compatible for outdoor applications (Zhang *et al.,* 2021). However, specific challenges are also associated with their usage; for example, Win DENDRO and LINTAB are more expensive and have limited application (Vannoppen *et al.,* 2017). Thus, this opens the door to more advanced methods, such as Panchromatic Images and Deep Learning software (Wang et al., 2024), and Pixel-Contrast Densitometry, which measures wood density based on photographs of the wood cross-section (Khudykh *et al.,* 2024).

Reliability and Challenges of Tree Ring Measuring Methods

Large Span Natural Archive – Given their diverse distribution and longevity, trees have provided the widest and most, most precise record of annual tree growth data spanning millennia. Providing data database for the age distribution and growth pattern of forest stands across the continents. Institutions and organisations like the International Tree-Ring Data Bank and many others have maintained tree ring records of more than 5,000 and measurement data files from peer-reviewed studies around the world (Guiterman *et al.,* 2024). These records have been instrumental not only in investigating tree age and growth patterns but also in providing natural archives for global environmental change studies.

Multi Proxy Analysis – Innovative methods of tree ring measurement have opened the door to a multi-proxy analysis. Using these methods has proven that, in some instances, combining ring width data with other properties, such as maximum latewood density and chemical

composition, provides the actually needed inter- and intra-ring data. It would enhance the reliability, more detection and correction and provide a more comprehensive understanding of the tree climate relationship (Xu *et al.,* 2020; Camarero *et al.,* 2023)

Use of Precise Sample Collection and Measuring Techniques – Over time, the scientific community has transformed from the use of crude, labour-intensive, and environmentally destructive methods of data collection. All thanks to advancementss in technology, the introduction of innovative methods and technologies has introduced greater precision and reliability to the methods.

Challenges of Tree Ring Measuring Methods

Variability in Growth Conditions – dealing with natural material with independent characteristics in a natural environment, can affect the accuracy of some methods. Some of the methods and techniques used may be limited to particular sampling locations and environments (Zhang *et al.,* 2021). Variation in environmental factors, such as local climate, soil quality, resource abundance, and disturbances, can affect tree growth, making it difficult to obtain the required ring information (De Micco *et al.,* 2019).

Variation in Wood Density and Structural Properties – Differences in methods of wood density and anatomical variations assessment, obtaining data from various sources can bring further complications in data compilation, especially when using an automatic feature detection algorithm (Martinez-Garcia *et al.,* 2021).

Technological Limitations – Advanced techniques like X-ray densitometry and isotope analysis are expensive and require special training; a lot of researchers in developing countries have limited access to such facilities (Gebrekirstos *et al*., 2014)

Conclusion

Trees, in general, and ring width in particular, have served as natural keepers of environmental records for many years, even before the invention of various data recording equipment. This write-up reviewed the destructive and non-destructive methods of tree ring width measurements. From the available data, it was observed that research is ongoing to improve the shortcomings of conventional methods, highlighting the importance of the tree age-climate relationship as well as its application in global change studies. More effort should be made by wood scientists in this part of the continent to match the efforts of their colleagues from other continents.

Recommendations

I. Despite the vast expansion of tree ring studies, an examination of internet searches reveals the scarcity of studies on the relationship between tree age and climate in West Africa, especially in Nigeria. Therefore, an effort should be made to complement the study gap.
II. Most of the studies encountered during the writing of this review, which are of Nigerian origin, including the most recent ones, still employ destructive methods. Future studies should focus on introducing innovative methods that will be compatible with tropical hardwood species.

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INNOVATIVE UTILISATION OF WOOD AND FOREST PRODUCTS AND SUSTAINABLE MANAGEMENT DEVELOPMENT

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ABSTRACT

This reviewed manuscript examined the importance of forestss to the human race, as provisioning ecosystem services such as food, raw materials, and medicinal resources derived from wood and non-wood forest products are highly valued in the tropics. Forests contribute to improved livelihoods, healthy landscapes and cities, and reduce the world's carbon and material footprints, thereby reducing climate change. The study found that sustainable use of natural resources, including forest products, is a key element of the development vision in the 2030 Agenda for Sustainable Development. The idea of sustainable forest management (SFM), an attempt to reflect the environmental, social, and economic benefits provided by forests, became widely accepted after the United Nations Conference on Environment and Development, which first saw international commitment to the concept of sustainable development more broadly. Forest resources and forest lands should be sustainably managed to meet the social, economic, ecological, cultural and spiritual needs of present and future generations. Innovation in wood and forest products identified four categories of innovative technologies as having the most potential for sustainable development in the forest sector, such as digital technology, biological technology, technical innovation in processes and products, social innovation, and innovative finance. Therefore,, the sustainable utilisation of wood and forest products should be encouraged, along with increased awareness of innovative utilisation methods.

Keywords: Forest, Innovation, Sustainability, Utilisation, Wood, Technology

1.0 INTRODUCTION

Contributing to climate change, biodiversity loss, and the emergence of new diseases, as well as in global efforts of moving towards sustainable economies. Forests and trees directly benefit at least 3.27 billion people (75 per cent of the non-urban population) who live within 1 km of a forest and outside urban areas (State of the World's Forests 2024). Provisioning ecosystem services, such as food, raw materials, and medicinal resources derived from wood and non-wood forest products, are highly valued in tropical forests, accounting for almost fifty per cent of their total estimated value. Urban populations also benefit from the provision of food, raw materials, in particular timber, and medicinal resources. Forests and trees are essential for planetary health and human well-being, providing a multitude of goods and services. Wood and non-wood forest products (NWFPs) play a crucial role in ensuring sustainable consumption and production, contributing to improved livelihoods, healthy landscapes and cities, and reducing the world's carbon and material footprints. Solid wood products store carbon and offer the opportunity to extend forest carbon benefits beyond conservation and restoration, as they support other climate and health benefits, such as temperature regulation and improved well-being, together with their lower carbon footprint, which supports sustainable and green cities (FAO, 2022).

Forests fulfill far more functions than simply the production of wood and non-wood products. Indeed, they are vital to achieving global sustainable development. They provide solutions to challenges including poverty

eradication, environmental sustainability, food security and agriculture, energy, clean water and watershed protection, biodiversity conservation, mitigation of and adaptation to climate change, combating desertification and land degradation, and disaster risk reduction. Forests are vital for creating green economies, including green industries (Duncan, 2018). More than 1.6 billion people worldwide – almost a quarter of the global population – depend on forests for food, medicines, and fuel, as well as their jobs and livelihoods, and 200 million people, including many indigenous people, directly depend on forests for their survival. Forests contain over 80 percent of the world's terrestrial biodiversity. As vital sources of energy, water, livelihoods, and biodiversity, forests play a crucial role in supplying the ecosystem services that society depends upon (FAO, 2022). Three-quarters of the world's freshwater, which is crucial for food production and human survival, among other things, is provided through forested catchments. Forests can help slow down or halt soil erosion and retain soil moisture, thereby combating desertification and providing protection against flooding. Healthy and resilient forests play a crucial role in mitigating and adapting to climate change. As the largest storehouse of carbon after the oceans, forests have the potential to absorb and store about one-tenth of the global anthropogenic carbon emissions projected for the first half of this century into their biomass, soils, and products – though at present about 10 percent of global greenhouse gas emissions are estimated to derive from deforestation. Forests make direct and tangible contributions to food security and indirect yet reliable resources to sustain rural livelihoods, particularly for vulnerable categories of people such as indigenous communities and women (Mfor et al., 2014).

1.1 SUSTAINABLE DEVELOPMENT

The sustainable use of natural resources, including forest products, is a crucial element of the development vision outlined in the 2030 Agenda for Sustainable Development. The concept of Sustainable Forest Management (SFM) gained widespread acceptance after the 1992 United Nations Conference on Environment and Development (the 'Earth Summit' in Rio de Janeiro), which marked a significant international commitment to sustainable development. The Forest Principles agreed upon at Rio emphasize that "forest resources and forest lands should be sustainably managed to meet the social, economic, ecological, cultural, and spiritual needs of present and future generations." This concept has been further defined by the Ministerial Conference on the Protection of Forests in Europe (Forest Europe) and adopted by the FAO (2022) as: "The stewardship and use of forests and forest lands in a manner and at a rate that maintains their biodiversity, productivity, regeneration capacity, vitality, and potential to fulfill relevant ecological, economic, and social functions at local, national, and global levels, without causing harm to other ecosystems."

The sustainable use of wood has significant potential to contribute cost-effectively to achieving carbon neutrality. This approach can also create synergies with rural economic recovery and sustainable circular economy innovation goals. Sustainable forest management is integral to sustainable agricultural and food systems. Notably, smallholders, local communities, and Indigenous Peoples manage at least 4.35 billion hectares of forest farmlands (FAO, 2022). Sustainable forest products, including wild meat and plants, play a crucial role in supporting livelihoods, particularly in terms of food security and nutrition. Over half of the global population relies on Non-Timber Forest Products for their well-being and livelihoods. Wild meat and plants contribute to food security and nutrition for communities residing near forests, particularly in tropical and subtropical regions. Incorporating these food sources into diets can also help reduce the costs of nutritionally adequate diets. However, these traditional food systems are often threatened by industrial agriculture and inadequate policy support. Communities dependent on forests and trees are primary beneficiaries of wood and non-wood forest products. They are key stakeholders

in ensuring the sustainable use of forest resources and developing thriving value chains that contribute to sustainable landscapes and the achievement of the Sustainable Development Goals (SDGs) (Byjus, 2020). The Sustainable Wildlife Management Program aims to address issues related to wild meat through projects in African, Caribbean, and Pacific countries. By developing innovative and collaborative approaches to wildlife use, the program seeks to conserve wild animals, protect ecosystems, and improve the livelihoods of indigenous peoples and rural communities reliant on these resources.

Sustainable wood-based solutions must be grounded in effective sustainable forest management practices, carefully balancing the potential trade-offs between wood production and the multifaceted roles of forests, including carbon sequestration, biodiversity conservation, and the provision of essential ecosystem services. To support sustainable wood production, a combination of approaches is necessary, including the application of silvicultural treatments alongside sustainable forest management, investments in restoration and afforestation initiatives, and policy and technical support to enhance the volume and reliability of sustainable agroforestry production. These efforts should be underpinned by technological innovations and incentives that promote material-efficient use, ensuring a balanced and sustainable approach to wood production.

1.2 INNOVATIVE TECHNOLOGY

Innovative technology encompasses both new and emerging technologies for new purposes. Innovation is increasingly recognised as a crucial factor in environmental protection and sustainable development within the forestry and forest-based industries. Innovation is essential for achieving the 2030 Agenda for Sustainable Development and the Sustainable Development Goals. It is an important accelerator for the transformation to more efficient, inclusive, and resilient societies, and for achieving global goals such as the eradication of hunger and poverty, as well as the sustainable management and use of natural resources. Innovation requires enabling policies, strong and transformative partnerships, investment, an inclusive culture that is open to and encourages new ideas, and a willingness to take calculated risks. The Innovative technology in the forest sector has the potential to provide new services and products, improve productivity and reduce costs, reduce waste, and improve the efficiency of resource and energy use. This further generates income and employment opportunities, conserves natural resources, and limits negative social, economic, and environmental impacts. Innovation in wood and forest products (Innovative et al, 2020) identified four categories of innovative technologies as having the most potential for sustainable development in the forest sector, such as digital technology, biological technology, technical innovation in process and products, social innovation and innovative finance:

Digital innovation can considerably facilitate accurate, cost-effective, and real-time monitoring of forest resources and the forest value chain. They can facilitate information sharing and capacity development, improving community participation and empowering local stakeholders. Digital enables breakthroughss in innovation for blockchain technology and securing electronic transactions. Digital gathers information and communication technologies (ICT) and geospatial technologies, such as drones, satellites, base observation, and other remote sensing technologies, including laser imaging detection. It improves silvicultural management, including refined site preparation, planting, and post-planting practices. Precision forest-based utilisation of digital technology reduced impact logging, winch-assisted harvesting, computer numerical control machining to optimize product design or wood processing portable sawmills, spindles, lathe to reduce waste, and use small diameter logs, drying technology that reduces energy use and cost, and microwave plasma technology to enhance wood properties. It is to improve the appearance, durability, and water resistance of the wood.

Process innovation can also create new uses for underutilised, hence undervalued, wood species, such as fast-growing small-diameter species. Process innovation directly improvess productivity and cost efficiency, reduces waste, and improves resource use efficiently. These products can create new uses for low–valued underutilized species. Wood scraps from processing mills and other wood waste significantly increase the wood recovery and recycling rate, thus generating additional economic and environmental benefits. This innovative product include engineer wood, such as cross laminated timber, mass timber, medium density fibre board, particle board, oriented strand board, veneer and plywood, engineer bamboo products, experimental bioplastic transparent wood to be used instead of glasses, biobased composite and cellulose nanomaterials with possible application for papers and packaging, food health, biosensor construction, electronic bioenergy that can reduce greenhouse gases emission and dependence on fossil fuel and biochar that increases soil carbon storage and enhances soil fertility. Product innovation has created a new generation of wood-based materials that can substitute non-renewable or more energy- or resource-intensive compositions for various possible uses. Innovative tree domestication effortss should expand to include native timber species, non-wood forest products, and other underutilised species for local utilisation, particularly in cases where these species are less utilised.

The forest-based industry has been evolving, and the reports provide insight into the development of many innovative wood-based products that have sustainability as one of their pillars. It can be seen in the engineered wood products used in mass timber construction, the recyclable and fully biodegradable composite materials for packaging, or on garments made of wood-based fibres that are produced without harsh chemicals. (Spathelf**, 2025**). Verkerk and Hassegawa (2022, however, warned of potential risks that could come with greater production and consumption of forest products, such as increased pressure on forests and forest-dependent people and unsustainable practices resulting in forest degradation and biodiversity loss. Using wood as raw material for making products can contribute to climate change mitigation according, This is because wood-based products store carbon and their use can help to avoid greenhouse gas emissions that occur over the lifetime of a product, as compared to other materials such as concrete, steel, plastics and synthetic fibres (Spathelf**, 2025**).

1.3 Innovations in Nigerian Wood Production Engineering

Innovations in wood production engineering hold immense potential to revolutionize the sector by enhancing efficiency and promoting sustainability. Modern technologies, including advanced machinery, automation, and digital tools, are poised to streamline processes, enhance productivity, and minimise waste. Moreover, sustainable forestry practices are increasingly prioritized to conserve Nigeria's diverse ecosystems and protect biodiversity. The adoption of innovative wood treatment methods not only ensures longer-lasting products but also enhances their quality and market competitiveness. Efficient supply chain management further optimises operations, minimising costs and delays while maximising resource utilisation. Overall, the integration of innovative practices is crucial for transforming Nigeria's wood production industry into a more robust, sustainable, and globally competitive sector, contributing to economic growth and environmental stewardship.

Technology has revolutionized the wood production industry in Nigeria with the introduction of automated cutting and carving machines. These machines have significantly improved efficiency and accuracy in the production process. Computer-aided design (CAD) software allows engineers and designers to create intricate wood designs with precision. This technology has enhanced the creativity and production capabilities of woodworkers in Nigeria. Incorporating customized wood finishing technologies has enabled Nigerian wood producers to meet the diverse needs of customers. These technologies offer a wide

range of finishes, from matte to glossy, enhancing the overall quality of the product. The use of wood drying kilns in Nigeria has improved the quality of wood products by reducing moisture content and preventing warping or cracking. This technology ensures that the wood is dried correctly and ready for use in various applications. Laser engraving machines have become an integral part of the wood production process in Nigeria, offering precise engraving and marking capabilities. This technology has opened up new opportunities for customisation and personalisation within the industry.

Woodwork technology continues to play a crucial role in Nigeria's economy. The sector provides employment and supports many livelihoods, especially in rural communities. Skilled woodworkers produce high-quality furniture, decorative items, and construction materials. These products are sought after both locally and internationally, contributing to Nigeria's export earnings. Moreover, woodwork education has been integrated into the Nigerian educational system. Vocational schools and technical colleges offer courses in carpentry and woodwork. This educational focus helps nurture the next generation of skilled artisans and craftsmen. (2025, Discipline, Innovations in Woodwork Technology: Nigeria Focus)

2. 0 PROBLEM STATEMENT

Despite the vast potential of wood and forest products to contribute to sustainable development, traditional utilisation practices often result in significant waste, limited value addition, and inadequate benefits for local communities. The challenges of forestry management include adapting to climate change, enhancing tree growth, increasing timber volume, and maximizing return on investment. The unsustainable harvesting, processing, and utilisation of forest products, such as timber and non-timber forest products, pose significant threats to forest ecosystems, including deforestation, degradation, and loss of biodiversity. It not only undermines the long-term viability of forests but also impacts the livelihoods of millions of people who depends on them for income, food and services. The innovative utilisation of wood and forest products, such as engineered wood products, biocomposites, and bio-based chemicals, offers opportunities for increased value addition, reduced waste, and improved environmental performance. However, the adoption of these innovations is often hindered by technical, economic and institutional barriers. The challenges lie in balancing the economic, social, and environmental dimensions of forest management, ensuring that forest products are utilised in a way that supports sustainable development while maintaining the health and integrity of the forest ecosystems. Therefore there is a pressing need to identify strategies and practices that optimize forest product utilisation, promote sustainable forest management, and support the development of local communities and economies.

2.1 AIM OF THE STUDY

This study aimed to contribute to the development of sustainable forest management practices that harness the potential of innovative wood and forest products utilisation, promoting economic development, environmental stewardship and social equity.

3.0 JUSTIFICATION OF THE STUDY

The innovative utilisation of wood and forest products is crucial for promoting sustainable forest management and development. Forests are a vital component of the global ecosystem, providing numerous economic, social and environmental benefits. However,, unsustainable forest management practices can lead to deforestation, biodiversity loss, and negative impacts on local communities.

4.0 DETERMINANTS OF DEMAND FOR WOOD.

Changes in population age structures indirectly affect demand for wood products. Increases in

working-age populations – currently being experienced in many developing countries – are often associated with a high demand for housing, and therefore for wood products used in construction and furnishings. It may be offset by contractions in demand in countries with ageing populations, though this also depends on cultural factors, such as family structure and degree of fragmentation. The competitiveness of economies in labour-intensive sectors may decline in the context of ageing populations, and also as wages and working practices improve, encouraging the relocation of labour-intensive industries (such as furniture manufacturing) to countries with more abundant labour (State of World Forest, 2024).

The rate and extent of urbanisation also affect demand for wood products, most obviously through demand for timber for housing, including wood used in construction, such as plywood for forms and scaffolding, as well as wood incorporated into building, window, and door frames, doors, and furniture. Urbanisation can also, however, reduce demand for wood fuel, as access to electricity and alternative forms of heating is generally easier in urban than in rural areas. Also, demand for wood products is significantly affected by changes in income, in complex and interconnected ways. All else being equal, increasing income – often characterised as the 'growth of the global middle class – tends to be associated with rising demand for wood products (apart from wood fuel, where generally demand falls), particularly those used in construction and housing. The highest rate of growth in consumption as income rises is generally observed in the consumption of paper and paper products, including packaging.

High-income and more highly educated populations also tend to be more sensitive to the environmental and social impacts of consumption and more willing to pay for ecosystem services (if given the opportunity and the information); this may feed through to a greater propensity to demand recycled or certified sustainable wood products, for example, with an accompanying impact on markets..

Finally, a key determinant of demand is, of course, the availability on the market of alternatives to wood, such as concrete or brick for construction, or metals or plastics for other products. The extent to which alternatives are used varies not only with their price but also with local culture, habits, and public policy. For example, the use of wood or its alternatives in construction may be influenced by government building regulations, as well as by the habits of architects and building firms and their familiarity with the products in question. This may hinder the adoption of new techniques, such as the use of cross-laminated timber for buildings, for example; however, the implementation of ambitious climate policies may lead to a greater utilisation of timber. The recent growth in concern over the impacts of plastics on ecosystems and human health may encourage the greater use of paper for packaging.

5.0 CONCLUSION.

Sustainable forest management in Nigeria involves planting trees to replace those harvested for wood production, implementing efficient waste management systems to minimise environmental impact, adopting renewable energy sources to power wood production machinery, and engaging in responsible logging practices to prevent deforestation and habitat destruction.

POLICY RECOMMENDATION

It is therefore recommended to achieve innovative utilisation of wood and forest products, as well as sustainable management development, through sustainable forestry certification programs. To ensure adherence to best practices, these programs should be promoted. The government should collaborate with local communities to support reforestation efforts and promote sustainable livelihoods. Additionally, educating workers and stakeholders on the importance of sustainability in wood production is crucial, as is regularly monitoring and evaluating the environmental impact of wood production activities.

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AWARENESS AND ATTITUDE TOWARDS BIOGAS UTILIZATION AMONG SAMARU RESIDENTS, ZARIA, KADUNA STATE, NIGERIA

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ABSTRACT
Global warming and the rising cost of conventional fuel, coupled with increasing demand for energy to meet domestic requirements and the lack of environment-friendly alternatives, have a a devastating effect on the environment. Observation shows that many studies have been conducted in search of renewable energy sources that can mitigate the negative consequences of using fuels that have an adverse effect on the environment; these include fuelwood/charcoal, which are commonly used in the majority of households. The studies on the environment-friendly alternatives include those on biogas as an energy source. This study assessed people's perception and attitude toward biogas as an alternative domestic fuel in Samaru. The methodology used was primary (questionnaire) sources of data, and descriptive statistics were used to present the outcome of the questionnaire survey. One hundred fifty respondents were used in five areas (Dan Raka, Hayin Dogo, Layin Zana, Hayin Danyaro, and New Extension). The findings show that less than 50% of the respondents were willing to adopt biogas as an alternative cooking fuel, while a slightly higher percentage were willing to adopt biogas for other domestic purposes, such as heating, lighting, and ironing.
Keywords: Biogas, Residents, awareness, fuel wood, domestic energy, Samaru.

INTRODUCTION
Energy is one of the three most essential requirements for sustainable development, alongside water and land (Barau, 2006). It is needed on a daily basis for various activities which cover both industrial and domestic requirements. The domestic energy requirements cater for activities such as cooking, heating, lighting and other similar domestic chores. Biogas is a mixture of methane and carbon dioxide produced by the bacterial degradation of organic matter and used as a fuel (International Energy Agency).

According to the University of Florida, biogas is the gaseous emissions from anaerobic degradation of organic matter (from plants or animals) by a consortium of bacteria. Biogas is principally a mixture of methane (CH4) and carbon dioxide (CO2) along with other trace gases.

(FAO) documents on renewable energy and biogas production.

Methane gas, the primary component of natural gas (98%), makes up 55-90% by volume of biogas, depending on the source of organic matter and conditions of degradation. Biogas is produced in all natural environments with low oxygen levels (O2) and degradable organic matter present. These natural sources of biogas include: aquatic sediments, wet soils, buried organic matter, animal and insect digestive tracts, and in the core of some trees. The choice of energy sources to choose from depends mainly on a family's level of income, size, and enlightenment on the various energy types available; for example, most people rely on electrical energy for domestic chores such as heating, ironing, cleaning, and etcetera however due to the epileptic nature of electricity supply; people are forced to seek for alternative sources of power to meet the requirements. For instance,, the use of power-generating sets to light homes, heat, and iron, etc., or the use of local charcoal-iron to iron laundry in the absence of electricity. The sources of domestic energy include electricity, gas, kerosene, solar, etc. However, Lekule (2001) noted that biomass is the primary source of energy for domestic use in Africa. There is a trend of over-dependence on biomass for fuel, and fuel wood is widely consumed in Kano city and rural areas, which is

having a detrimental effect on the most densely populated areas in the state (Ahmad, 2006).

Out of several domestic energy sources to choose from, fuelwood happens to be the popular choice. It can be attributed to the purchasing power of the majority of people living in the study area, who thus opt for fuelwood as a significant domestic energy source. Ahmad (2006) noted that the ever-increasing demand for fuelwood to meet energy requirements has put most parts of Sudano-Sahelian Nigeria under the threat of deforestation. The catalysts of deforestation include the lack of effective alternative energy options for the majority of the people. Researchers such as Barau (2006), Ahmad (2006), and Cotthem (2010) identified the lack of alternatives as the main reason that forced many households to adopt biomass or firewood to meet their domestic energy requirements. Barau (2006) lamented that the energy crises and the lack of affordable alternatives due to changing government policies have forced the majority of the population down the energy ladder. This means that people who previously could afford cooking gas were forced to adopt kerosene. Those who could previously afford kerosene were forced to adopt firewood or charcoal. Barau (2006). This trend continues down the energy ladder, affecting various income classes. The lowest in the energy ladder were those who previously used firewood, but can no longer afford it as an energy source and thus will be forced to adopt crop stumps, animal dung, and other harvest residues that are left on the farm as soil cover. It leads to more land being left bare and thus increasing the land's susceptibility to degradation (Yakubu, 2010). Barau (2006) also observed that firewood is widely consumed in cities, to the detriment of the environmental stability of high-population-density areas such as Kano. Apart from fuel wood, there are other fossil fuels and renewable energy sources (such as solar, biofuels, wind and etcetera), however, he argued that despite the fact Kano lacks means of self-sufficiency in fossil fuels (because it lacks oil and huge forest belts), the State has good potentials for generation of alternative sources of energy which are cleaner and ecologically sound. However, some of these technologies are expensive and cannot be implemented by the average Nigerian; thus, the research for an affordable and environmentally friendly alternative necessitated this study. The search for alternative energy sources that will be cost-effective and applicable to third-world nations (including Nigeria) is a priority of global concern. The choice of environmentally friendly energy options is a significant step forward in addressing the menace of desert encroachment in sub-Saharan Africa, particularly, and climate change at the global scale (Zakariya'u, 1999). Studies in Nigeria have shown that the urban poor and rural households still depend on biomass for their energy needs. Akingbami et al. (1996), as cited in Mshendete and Parawira (2009), identified feedstock substrates for an economically feasible biogas in Nigeria to include water lettuce, water hyacinth, dung, cassava leaves, processing waste, urban refuse, solid waste (including industrial waste), agricultural residues, and sewage. Due to this trend and its subsequent problems, an alternative energy source needs to be researched and adopted, especially in areas already affected by desert encroachment and drought as a result of deforestation for both industrial and domestic purposes. This study aims to evaluate people's perception and attitude towards biogas as an alternative fuel for domestic use.

MATERIALS AND METHODS

Study Area

Samaru is a growing urban settlement within Zaria. The area has a cosmopolitan characteristic owing to the presence of several educational institutions, which attract people from all over Nigeria for academic and employment purposes. It is located approximately at latitudes 110°10` and 110°11' North and longitudes 7°0'37" and 7°0'40 "East. The area is located in Sabon Gari LGA, situated between ABU Zaria, Basawa village, and Bomo (Fig. 3 .1). The origin of Samaru is not directly traced to a primordial stream with a tree, but rather to a place known as Gangan Uku or Old Samaru. Its expansion, however, started with the establishment of the Nigerian College of Art, Science, and Technology in 1951. Later in

1962,, the college was transformed into Ahmadu Bello University (ABU), and this led to a rapid influx of people into the area for both educational and occupational reasons. Today, other institutions are added to ABU, leading to a further increase in population. Samaru has a climate similar to Zaria, with distinct variations in rainy and dry seasons (Sawa and Abdulhamid, 2009).

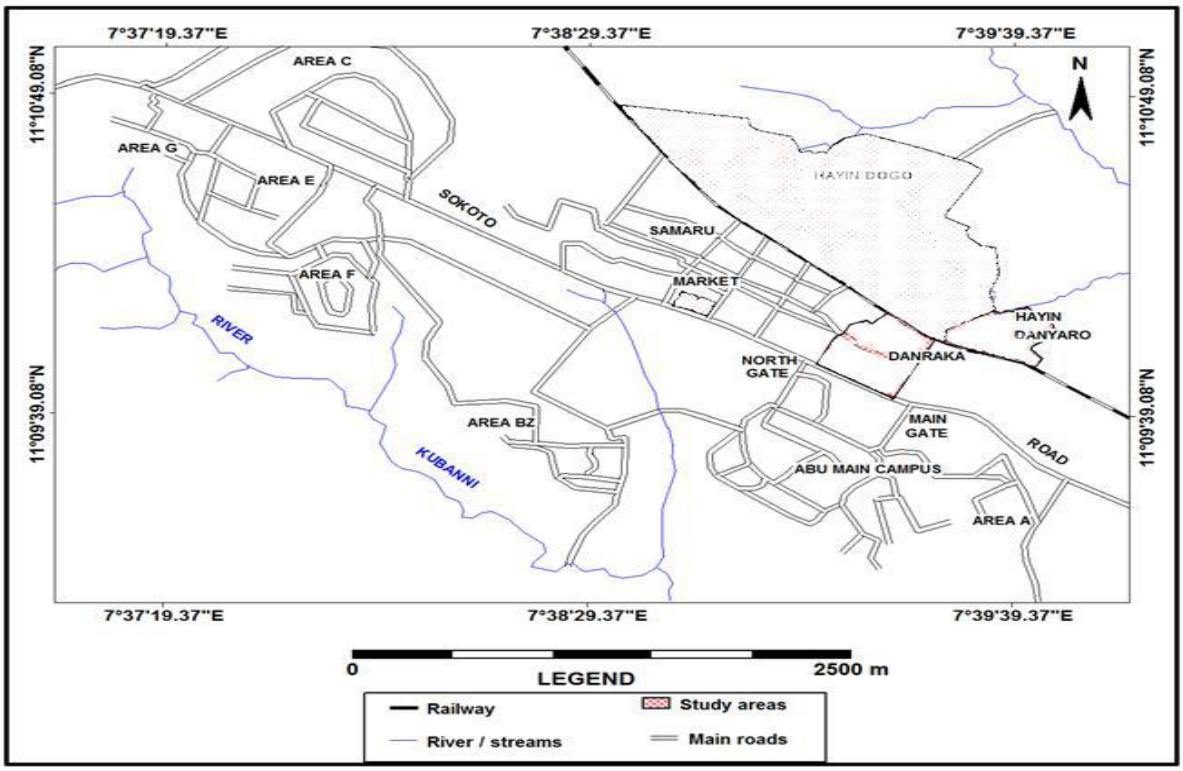

Fig. 1: A Map showing the location of the study area

Method of Data Collection

A questionnaire was administered in the study area aimed at assessing people's awareness and attitude towards biogas as an alternative domestic fuel in Dan raka, Hayin dogo, Layin zana, Hayin danyaro and the new extension. The reason is to ensure uniformity among the 150 respondents who were administered the questionnaire. The respondents were divided into the following age groups: 18-35 years, 36-50 years, and 51 and above. It was done to examine the attitudes of various age groups towards accepting a new idea; and also because one of the major problems faced by biogas is a lack of awareness and the issue of social acceptance regarding the generation of cooking fuel from waste materials. The questionnaire is structured in such a way that the respondent's level of enlightenment, income levels, type of energy utilised for cooking and other domestic purposes were scrutinised. An accidental sampling technique (a non-probability method) was adopted for this research. This is due to the convenience it offers when conducting the field exercise. It involved meeting people at random within the designated study areas. A total of 30 respondents were administered the questionnaire in each of the chosen locations: Dan Raka, Hayin Dogo, Layin Zana, Hayin Danyaro, and New Extension. Areas of descriptive statistics were used to represent the results from the responses obtained from the respondents, aiming to make the analysis of the trend more straightforward. It included the use of tables, bar charts, and pie charts.

RESULTS AND DISCUSSION

Age of the Respondent

Figure 1 shows that 40% of the respondents fell within the age bracket of 18-35, 36% were aged 36-50, and 24% were aged 51 and above. This means that the age bracket of 18-35 has a higher number of respondents in this study.

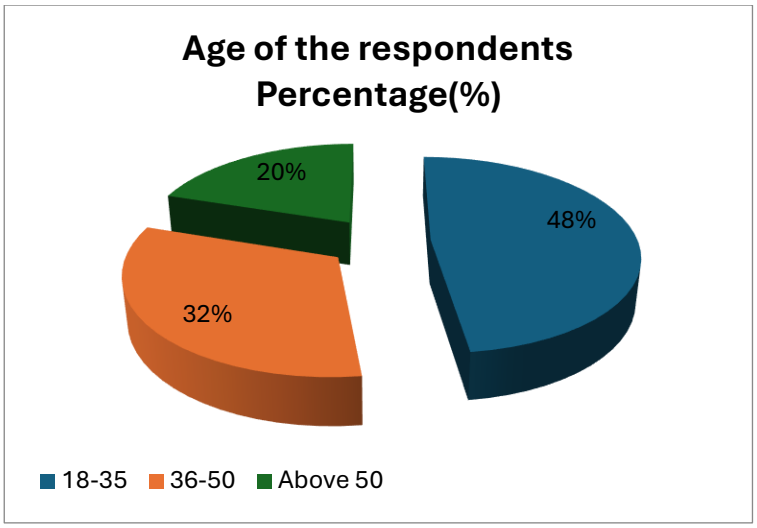

Figure 1: Age of the respondents, Percentage (%)

Level of Income

Table 1 shows the level of income of the respondents; 40% earn less than ₦5000, 13.3% earn Between ₦5,000-N10,000, 41.3% earn above ₦10,000, while 5.3% stated that their levels of income were not specified in the options.

Table 1. Level Income

1. Location	2. Less than ₦5000	3. Btw ₦5001-10000	4. Above ₦10000	5. Others	6. Sub-total
7. Danraka	8. 14	9. 4	10. 11	11. 1	12. 30
13. Hayin Dogo	14. 12	15. 3	16. 13	17. 2	18. 30
19. Hayin Danyaro	20. 13	21. 5	22. 9	23. 3	24. 30
25. New extension	26. 11	27. 4	28. 14	29. 1	30. 30
31. Layin zana	32. 10	33. 4	34. 15	35. 1	36. 30
37. Total	38. 60	39. 20	40. 62	41. 8	42. 150

Level of Education

Table 2 shows the level of education of the respondents: 17.3% had Islamiyya education, 8% were at the primary school level, 14.6% had secondary school education, 52% had tertiary level education, while 8% stated that their level of education was not listed in the options.

Table 2. Level of Education

Location	Islamiyya	Primary level	Secondary level	Tertiary level	Others	Sub-total
Danraka	6	1	4	17	2	30
Hayin Dogo	4	6	7	7	6	30
Hayin Danyaro	7	3	2	16	2	30
New extension	5	0	5	19	1	30
Layin zana	4	2	4	19	1	30
Total	26	12	22	78	12	150

Type Energy Utilized for other Domestic Purposes

Table 3 shows that 78.6% use electricity, 6.67% use a power-generating set, while 14.6% use firewood or charcoal for domestic purposes, such as heating, lighting, and ironing. This trend could be attributed to the epileptic nature of electricity supply as obtained nationwide; this leaves the majority with no options other than to resort to other means of getting their domestic activities done. The usual choice for ironing is by the use of locally-made iron that requires charcoal as an energy source, and thus the demand for fuel wood/ charcoal increases with increasing population.

Table 3. Energy Utilized for other Domestic Purposes

Location	Solar	Electricity	Gas	Kerosene	Fuelwood/charcoal	Generating set	Others	Sub-total
Danraka	0	25	0	0	3	2	0	30
Hayin Dogo	0	24	0	0	5	1	0	30
Hayin Danyaro	0	23	0	0	5	2	0	30

128. New extension	129. 0	130. 23	131. 0	132. 0	133. 4	134. 3	135. 0	136. 30
137. Layin zana	138. 0	139. 23	140. 0	141. 0	142. 5	143. 2	144. 0	145. 30
146. Total	147. 0	148. 118	149. 0	150. 0	151. 22	152. 10	153. 0	154. 150

Type of Energy Utilized for Cooking

Table 4 shows that 23.9% of the respondents use electricity, 32% use gas, while 44% use firewood or charcoal for cooking. It indicates that a majority of respondents use firewood for cooking in their homes. This trend was similarly noted in a study conducted by Zakariya'u (1999) and Barau (2006). Moreover, some people, especially the elderly, usually insist that food cooked with firewood tastes better, thus being more palatable. For such individuals, the idea of using any fuel other than wood to prepare food is absurd.

Table 4. Energy Utilized for Cooking

155. Location	156. Solar	157. Electricity	158. Gas	159. Kerosene	160. Fuelwood/charcoal	161. Others	162. Sub-total
163. Danraka	164. 0	165. 2	166. 8	167. 10	168. 10	169. 0	170. 30
171. Hayin Dogo	172. 0	173. 2	174. 7	175. 11	176. 10	177. 0	178. 30
179. Hayin Danyaro	180. 0	181. 1	182. 5	183. 13	184. 11	185. 0	186. 30
187. New extension	188. 0	189. 2	190. 7	191. 9	192. 12	193. 0	194. 30
195. Layin zana	196. 0	197. 1	198. 1	199. 5	200. 23	201. 0	202. 30
203. Total	204. 0	205. 8	206. 28	207. 48	208. 66	209. 0	210. 150

Awareness on Environmental Consequences of Fuel Wood

Table 5 shows that an overwhelming majority of 72% of the respondents were aware of the environmental consequences of using firewood, such as the emission of CO2 and the greenhouse gas effect, while only 28% of the respondents stated that they were unaware of these consequences. This trend is encouraging, as it indicates that people from various walks of life are becoming aware of the environmental impacts of wood fuel consumption.

Table 5. Awareness of the Environmental Consequences of Using Fuel Wood

211. Location	212. Yes	213. No	214. Sub-total

215. Danraka	216. 21	217. 9	218. 30
219. Hayin Dogo	220. 21	221. 9	222. 30
223. Hayin Danyaro	224. 22	225. 8	226. 30
227. New extension	228. 25	229. 5	230. 30
231. Layin zana	232. 19	233. 11	234. 30
235. Total	236. 108	237. 42	238. 150

Awareness of Biogas

Table 6 shows that only 48% of the respondents were aware of biogas, while 52% of them were unaware of it. From this table, it can be seen that, more than halve of the respondents are unaware of biogas itself talk less of considering it as an alternative source of domestic energy, more enlightenment is needed to ensure that people are made aware of environment friendly alternatives that can also be cost effective, also noted by Mshendete and Parawira (2009).

Table 6. Awareness of Biogas

239. Location	240. Yes	241. No	242. Sub-total
243. Danraka	244. 17	245. 13	246. 30
247. Hayin Dogo	248. 16	249. 14	250. 30
251. Hayin Danyaro	252. 10	253. 20	254. 30
255. New extension	256. 21	257. 9	258. 30
259. Layin zana	260. 8	261. 22	262. 30
263. Total	264. 72	265. 78	266. 150

Adopting Biogas for Cooking

Table 7 shows the responses given when respondents were asked if they could consider adopting biogas as a replacement for their present energy source used for cooking; 38.6% stated 'yes', 26.6% said 'no', while 34.6% were undecided. The response is fair with the hope that with more enlightenment, more people will be able to decide in the affirmative.

Table 7. Consideration for the Adoption of Biogas for Cooking

267. Location	268. Yes	269. No	270. Undecided	271. Sub-total
272. Danraka	273. 13	274. 5	275. 12	276. 30
277. Hayin Dogo	278. 7	279. 3	280. 20	281. 30
282. Hayin Danyaro	283. 11	284. 13	285. 6	286. 30
287. New extension	288. 14	289. 8	290. 8	291. 30
292. Layin zana	293. 13	294. 11	295. 6	296. 30
297. Total	298. 58	299. 40	300. 52	301. 150

Adopting Biogas for Other Domestic Purposes

Table 8 presents the responses to the question of whether respondents were willing to adopt biogas for domestic purposes other than

cooking. Specifically, 41.3% stated 'yes', 17.3% stated 'no', while 41.3% of the respondents were undecided. It indicates that a slightly higher percentage of the respondents were willing to utilize biogas to cater for domestic purposes other than cooking, thus people might be inclined towards considering biogas to provide energy for other purposes, such as electricity.

Table 8. Consideration for Adoption Biogas for other Domestic Purposes

302. Location	303. Yes	304. No	305. Undecided	306. Sub-total
307. Danraka	308. 12	309. 4	310. 14	311. 30
312. Hayin Dogo	313. 13	314. 5	315. 12	316. 30
317. Hayin Danyaro	318. 11	319. 8	320. 11	321. 30
322. New extension	323. 17	324. 4	325. 9	326. 30
327. Layin zana	328. 9	329. 6	330. 15	331. 30
332. Total	333. 62	334. 26	335. 62	336. 150

Willingness to adopt the use of Bio digester

Figure 2 shows that responses about whether the responses were willing to install a bio digester; 40% indicates 'yes', 14.6% stated that if their landlords will allow it, 22.6% think it will be too dangerous to install in a home. In comparison, 22.6% stated that they had reasons other than those mentioned. It suggests that fewer than half of the respondents may be willing to have a biodigester installed in their homes. However, this trend might improve if more research is conducted to ensure that safer and more efficient biogas plants are designed to suit homes with limited space.

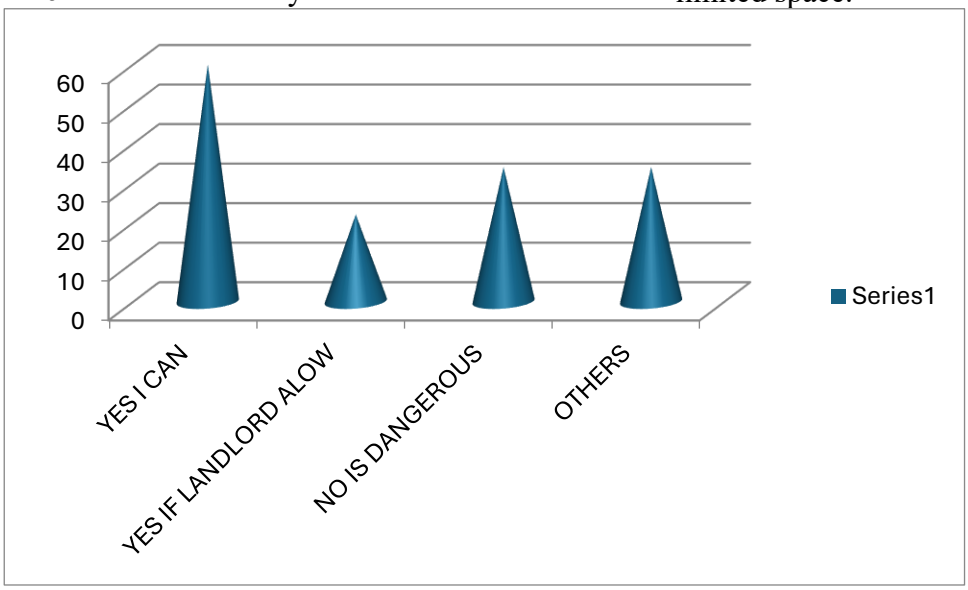

Figure 2: Willingness to adopt the use of biodigester

CONCLUSION AND RECOMMENDATIONS

The following conclusions can be drawn from the study's aforementioned facts. The importance of energy in everyday life cannot be overemphasized. The search for alternative energy sources is a necessity aimed at mitigating the negative consequences of our present energy

sources. Biogas is one of the environmentally friendly alternatives that will hopefully minimise environmental degradation and aid in reducing greenhouse gas emissions.

The availability of environmentally friendly renewable energy options needs to be communicated to people so they can stay informed about the choices they have. The misperception or misconception of people about the phobia of biogas and its usage needs to be adequately addressed so that the cultural use of fuel wood can be reduced to a minimum. All findings, including those from this study, need to be adopted and adapted for use in collaboration with institutions involved in promoting indigenous engineering projects that can solve current problems. It has been observed that the level of income, level of education, and age play a significant role in the choice of energy utilised for cooking and other domestic purposes. Due to the nature of anaerobic digestion to produce biogas and the versatility of materials that can be used as a feedstock for the gas especially human faeces and waste water, a lot of people are somewhat reluctant to use such a gas to cook the food they are going to eat. However, some other more enlightened respondents stated that it does not matter. A higher number of respondents, however, were willing to utilise biogas for other domestic purposes, such as lighting, heating, and ironing. It involves converting the biogas fuel to electrical energy. It had been observed that the significant problem with the adoption of biogas in this part of the world is the social acceptability problem. Perhaps the issue of converting waste to electricity might be more readily acceptable, so if the dumpsites are to be taken care of, conversion of biogas to electricity should be considered as an option. Further research on this is required. The Ministry of Environment has been active in sensitisation programs that involve collaboration with the telecommunications industry, asking people to stop cutting down trees to avoid deforestation and desertification. The truth is, such a campaign will not work if people are not supplied with options that are affordable and simple enough to adopt. The engineers are tasked with providing such an option to be promoted by government agencies and other donor organisations, ensuring that it is made available to the average Nigerian.

RECOMMENDATIONS:

There is a need for more research to be conducted in the area of renewable energy sources in order to reduce over-dependence on firewood as an energy source. Such a strategy will go a long way in ensuring that fewer trees are cut down, and they are done only when necessary. This will ensure that our forest reserves are restored, the ecological balance is maintained, and the negative effects of anthropogenic activities are mitigated. The majority of waste in this part of the world comprises the bio-degradable portion, which can be used to produce biogas anaerobically. Hence, I recommend the following;

- Research on the construction of a simple combined digester for cooking purposes that will be affordable. Such innovations will protect the innocent users, especially the household women who suffer various respiratory and eye problems as a result of smoke and gases.
- An enlightenment campaign on the advantages of using clean energy, such as biogas, for domestic purposes should be seriously considered. This prospect of utilizing waste to produce energy should be seriously looked into, as it could help solve our environmental problems while providing a source of livelihood to unemployed members of the community.

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THE IMPACT OF URBAN NEW EXTENSION ON THE CARBON SEQUESTRATION OF TREES OUTSIDE FOREST (TOF) IN SOKOTO METROPOLIS

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ABSTRACT

Trees outside Forest (TOF) are essential resources that contribute to the global carbon cycle, thereby mitigating climate change. Urban areas are significantly expanding with increasing populations, and these expansions are often done at the expense of available vegetation, resulting in an increase in CO2 emissions in the atmosphere. It is in this view that the study assessed the impact of urban new extension on the carbon sequestration potential of TOF. Two areas were selected from the metropolis, Gagi and Nakasari, as these two areas were recently observed to have undergone serious expansion. Due to the scattered nature of the trees in the study area, a systematic sampling technique was adopted. A 50m line transect was laid and measurements of tree characteristics were taken at every 10m interval. Images were downloaded from the United States Geological Survey (USGS) to detect changes in the study epochs (2000, 2010, and 2023). The Above-ground Biomass (AGB) and Below-ground Biomass (BGB), as well as the Carbon Stock (CS), were estimated. The study obtained a value of 28.306 t ha^{-1}, 5.661 t ha^{-1} and 16.984 t ha^{-1} for AGB, BGB and CS, respectively, and the amount of carbon sequestered was 62.33CO_2e ha-^{1}. Changes in vegetation were also observed in the Gagi area, where the vegetation reduced from 17.48% to 12.01% and 6.38% in 2000, 2010, and 2023, respectively. In Nakasari, the changes were from 25.24% to 14.27% and 9.09% in 2000, 2010, and 2023, respectively. However, changes in the vegetation resulted in the reduction of the carbon sequestration potential of trees in the study areas. To overcome such challenges, more trees should be incorporated in urban areas during these expansions to increase the carbon sequestration potential of TOF in the study area.

INTRODUCTION

Urban areas in the past were of manageable sizes in Nigeria, but due to an increase in population and the need for infrastructural development to meet the demand of the growing population, tree vegetation is being cleared, thereby distorting the ecological functions provided by the trees. Climate change, a global issue, is caused by the anthropogenic emission of greenhouse gases (GHG), and a large proportion of these emissions, especially carbon dioxide (CO2), originates from urban areas, thereby accelerating climate change (FAO and UNEP, 2020).

Trees outside Forests (TOF) are trees found in areas not designated as forest, but predominantly in agricultural land and urban areas (FAO, 2013). Trees that are not found in agricultural or urban areas but are used as windbreaks, shelterbelts, corridors and riparian tree formations that have at least 25 meters in length and less than 20 meters in width are also considered TOF (Havu *et al*., 2022). TOF offers a variety of ecosystem services, ranging from carbon sequestration to cooling local temperatures, stormwater mitigation, and improving air quality (Pataki *et al*., 2011; Pickett *et al*., 2011).

Terrestrial plants, as reported by the IPCC (2019), remove approximately 60 billion tons of carbon from the atmosphere each year. Studies have shown that aside from struggling to decrease the release of CO_2 in city atmospheres, it is also possible to absorb carbon from the atmosphere and cumulatively trap it in different components of the urban environment (Ariluoma *et al.*, 2021). This application of CO_2 is referred to as carbon sequestration, and urban

trees in parks and forested areas can, in fact, remove and store large amounts of carbon in belowground and above-ground woody biomass (Ngo and Lum 2018).

Urban areas are experiencing a significant increase in carbon dioxide (CO_2) emissions due to several interconnected factors. One of the primary drivers is the rapid urbanisation and population growth, resulting in increased energy demands. As more people migrate to cities, there is an intensified need for housing, transportation, and industrial activities, all of which rely heavily on fossil fuels. Urban new extensions can have significant effects on the carbon sequestration potential of trees outside forests. These areas often involve deforestation and land development, resulting in the removal of existing trees and vegetation. As a result, there is a reduction in the overall carbon sequestration capacity, as mature trees are lost and replaced with buildings and infrastructure (Aronson *et al*., 2014).

Urbanization has led to changes in microclimates, altered precipitation patterns, and increased air pollution, which can negatively impact the health and growth of remaining trees, further reducing their carbon sequestration potential (Yosef *et al*., 2018). Hence, there is a need to assess the impact of this development on the carbon sequestration potential of trees.

Due to the growing concerns about climate change resulting from increased carbon dioxide concentrations in the atmosphere. Considerable interest has been drawn to the possibility of increasing the rate of carbon sequestration through changes in land use and forestry, as well as through geo-engineering techniques such as carbon capture and storage. (Sample, 2017).

However, urbanization and the expansion of cities through new extensions have led to significant changes in the landscape and environment in the study area. One critical aspect of this transformation is the alteration of green spaces and the potential impact on carbon sequestration by trees outside traditional forested areas. As cities expand, the presence of trees within these urban extensions becomes increasingly essential for mitigating carbon emissions and supporting urban sustainability. Hence,, it is paramount to study the extent of these developments and their effect on TOF to provide information essential for addressing climate change, promoting sustainable urban development, and ensuring the well-being of urban populations and ecosystems.

MATERIALS AND METHODS

The study was conducted in the Gagi and Nakasari areas of Sokoto metropolis. These areas are located at latitudes 13.0539°N and 13.0450°N, and longitudes 05.2736°E and 05.2704°E for Gagi and Nakasari, respectively (Figure 1)

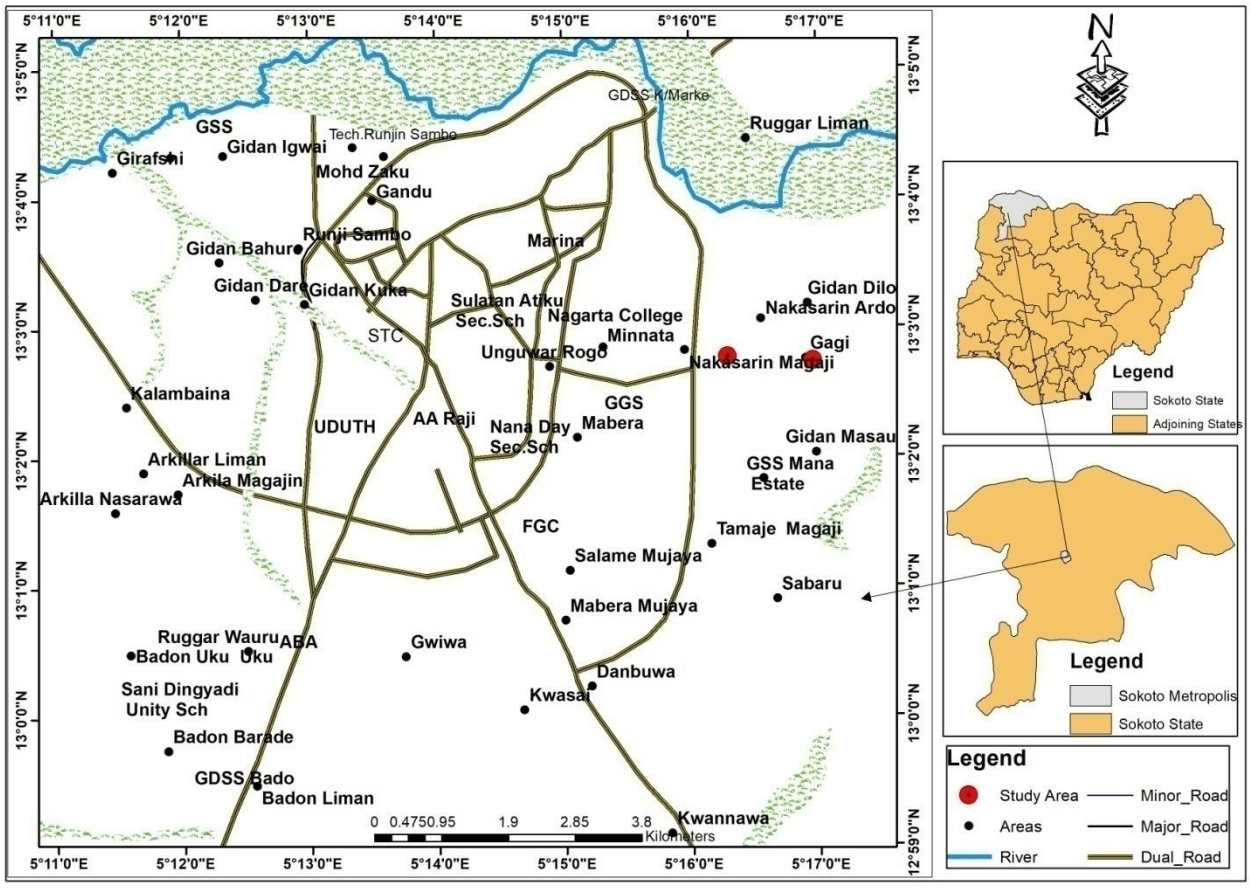

Figure 1: Map of Sokoto Metropolis showing the study area

The semi-arid climate corresponds to the Koppen's tropical wet and dry (Aw) climate classification. Annual rainfall averages around 600mm, while the average daily temperature is approximately 36°C (Adamu *et al*., 2017; Sanni *et al*., 2012). The mean temperature ranges from 38°C to 44°C or higher around April. It is characterized by a long and severe dry season, lasting from October to May, and a short but intense wet season from May to June until September to October. The mean relative humidity reaches its peak of over 90% in August, with the lowest values in December and January (10-30%).

The vegetation is the Sudan savannah type, composed of grasses and sparsely distributed drought-tolerant tree species (Isah and Sokoto, 2019). Generally, the vegetation around the metropolis consists mainly of short and stunted shrubs and grasses. The soil is predominantly ferruginous tropical type. It is texturally sandy with pH ranging between 6 and 7.

Data Acquisition

Image acquisition: Satellite scenes of the study area were downloaded from the United States Geological Survey.

Image Pre-processing

Raw remotely sensed image data contains flaws or deficiencies, and correction is required before image processing. The pre-processing includes radiometric, geometric, and atmospheric corrections. Firstly, the images were orthorectified by projecting the images to the Universal Transverse Mercator (UTM) coordinate system and the world Geodetic System 1984 (WGS 84), zone 31N, using the TerrSet Idrisi software..

Sampling Procedure

Systematic sampling was used due to the scattered nature of the trees in the study areas, as this ensured a wide coverage of trees in the study area. A 50m line transect was laid and measurements of tree characteristics were taken at every 10m interval.

Data Collection

Data were collected using both remote sensing techniques and field surveys. The images acquired were used to assess the LULCC for different epochs considered in the study (2000, 2010, and 2023). A field survey was also conducted to collect the biophysical characteristics of the trees in the study area. The parameters measured include the DBH, height, diameter at the base, middle, and top of the trees.

Biomass Estimation

Biomass estimation involves the estimation of important characters such as the aboveground biomass and the belowground biomass.

Aboveground Biomass (AGB)

AGB include all living biomass above the soil. The AGB was obtained by multiplying the tree volume and its wood density, which was computed using equation 1:

$$AGB_{(t\ ha^{-1})} = V \times WD \quad (1)$$

V =Volume of the tree, WD =Wood density

The volume of the tree was estimated using Newton's formula (Eqn. 2)

$$V = \frac{\pi h}{24}(\mathrm{D}^2{}_b + 4\mathrm{D}^2{}_m + \mathrm{D}^2{}_t) \quad (2)$$

Where: V = volume of tree, h = total height of the tree, D_b = diameter at base, D_m = diameter at middle, D_t = diameter at top and π =3.142 (a constant).

The density for various tree species encountered was retrieved from global wood density data.

Belowground Biomass (BGB)

The BGB was estimated using a root-to-shoot ratio of 0.20 (Eqn. 3).

$$BGB_{(t\ ha^{-1})} = 0.20 \times AGB_{(t\ ha^{-1})} \quad (3)$$

Total Carbon Stock (TCS)

The TCS was calculated by summing the carbon stock,, which includes AGB and BGB (Eqn. 4).

$$TCS_{(t\ ha^{-1})} = C(AGB) + C(BGB) \quad (4)$$

The TCS was converted to tons of CO_2 equivalent (t co_2 eha^{-1}) values by multiplying it by $^{44}/_{12}$ or 3.67, which is a ratio of of carbon dioxide to carbon. These are the standards for reporting carbon stock estimates in the carbon market.

Data analysis

Data were analysed using SPSS, and spatial analysis was done using ArcGIS 10.5.

RESULTS AND DISCUSSION

Summary Statistics

The data obtained from the field and the parameters computed were summarised and presented in Table 1. It shows the average, minimum, maximum values and standard deviation of the variables obtained.

Table 1: Summary Statistics

Variables	**Minimum**	**Maximum**	**Mean**	**Std. Deviation**
Db	5.47	93.00	28.88	28.65
Dbh	5.06	86.00	22.93	24.81
Dm	4.42	82.00	21.57	24.67
Dt	3.68	80.00	20.15	23.30
Height	4.00	17.00	9.46	3.01
Volume	0.01	8.79	1.06	2.24
Biomass	0.01	10.98	1.17	2.75
Carbon	0.003	5.49	0.59	1.38

Db: Diameter at base, Dbh: Diameter at breast height, D_m: Diameter at middle, D_t: Diameter at the top.
Source: Field survey (2023)

Average Biomass Estimation
The average values of the biomass estimated were presented (Table 2) for the two locations considered. The values obtained for the average AGB (0.132), BGB (0.026), AGB (2.580), and BGB (0.516) for Nakasari and Gagi, respectively, were low, which is an indication of the impact of urban expansion on carbon sequestration of trees in the area. It is in conjunction with the observation made by Yosef *et al*. (2018) that urbanisation has negatively affected the health and growth of trees in urban areas.

Table 2: Average Biomass Estimation

Location	**Average ABG (t ha^{-1})**	**Average BGB (t ha^{-1})**
Nakasari	0.132	0.026
Gagi	2.580	0.516

AGB = Above ground biomass, BGB = Below ground biomass
Source: Field survey, 2023

Total Biomass and percentage Contribution of Carbon pools Estimated
The total biomass and the percentage contribution of the carbon pools are estimated from the above and below ground biomass as presented in Table 3. The value (33.97) was low due to the scant vegetation cover observed in the study area. The estimated total biomass for this study was low compared to the values (71.94), (53.50) and (100.68 t ha^{-1}) as obtained by Behera *et al*. (2022), Ibrahim *et al*. (2018) and Sitorus and Rauf (2017) respectively and above the range (16.38 – 30.53) obtained by Sharma *et al*. (2020). The AGB pool tends to contribute more to the carbon stock (83.33%) than the BGB (16.67%).

Table 3: Total Biomass and percentage Contribution of Carbon pools Estimated

Variables	**Total Biomass (t ha^{-1})**	**% contribution of the pools**
Total AGB	28.31	83.33
Toatal BGB	5.66	16.67
Total Biomass	33.97	
Total CS	16.98	
Total $CSs_{equestered}$	62.33	

AGB = Aboveground Biomass, BGB = Belowground Biomass, CS = Carbon Stock & $CS_{Sequestered}$ = Sequestered Carbon

Land Use Land Cover (LULC) Change (2000-2023)

The LULC changes for the periods between 2000 and 2023 were detected for the two locations. The LULC maps, as presented for Nakasari (Figures 1a – 1c) and Gagi (Figures 2a – 2c), show a decline in vegetation cover, which is due to the expansion of built-up areas as the population increases.

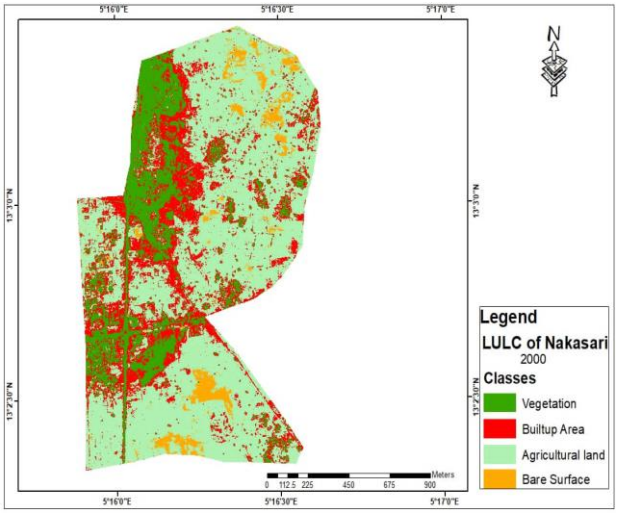

Figure 1(a): LULCC for Nakasari (2000)

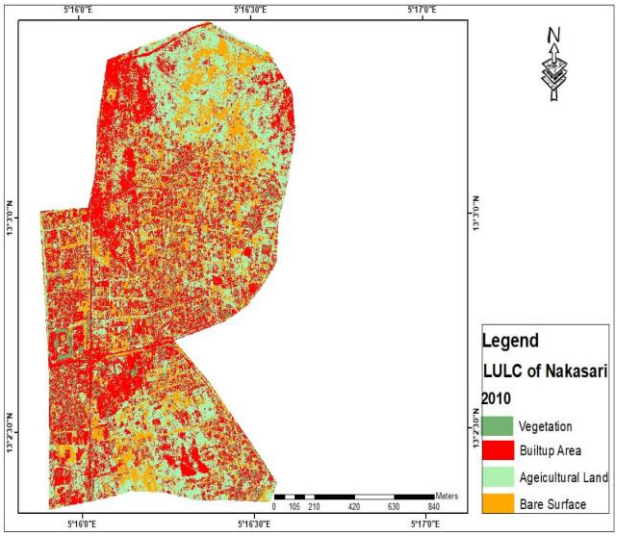

Figure 1(b): LULCC for Nakasari (2010)

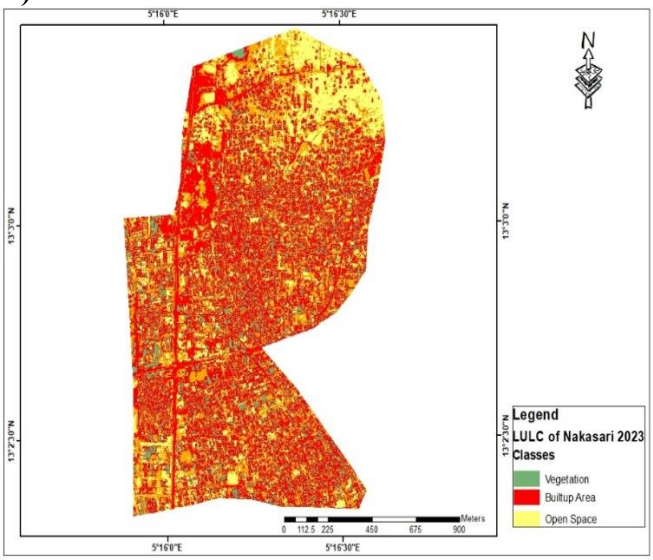

Figure 1(c): LULCC for Nakasari (2023)

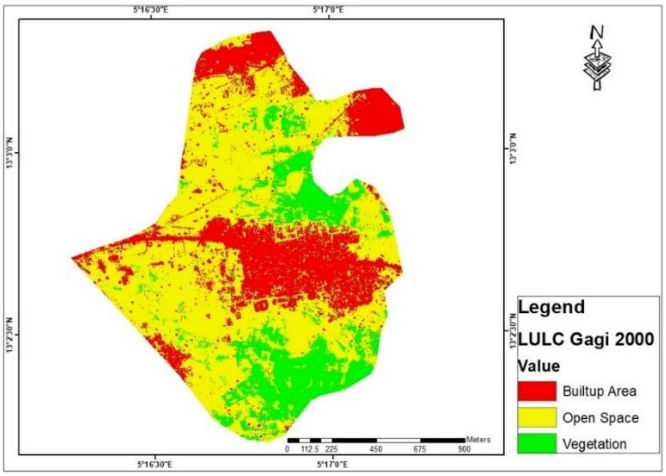

Figure 2(a): LULCC for Gagi (2000)

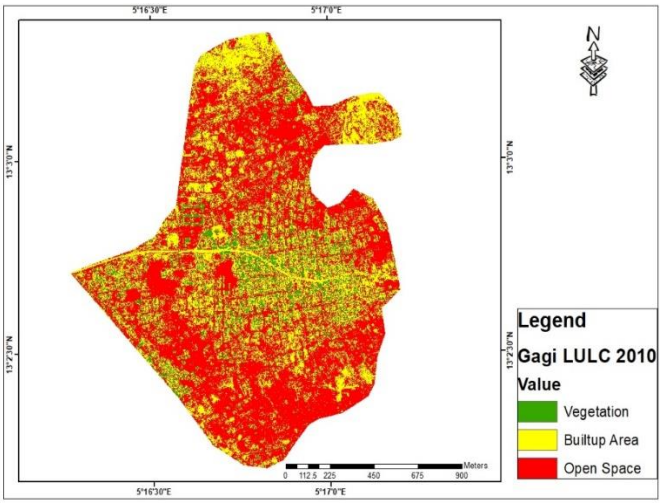

Figure 2(b): LULCC for Gagi (2010)

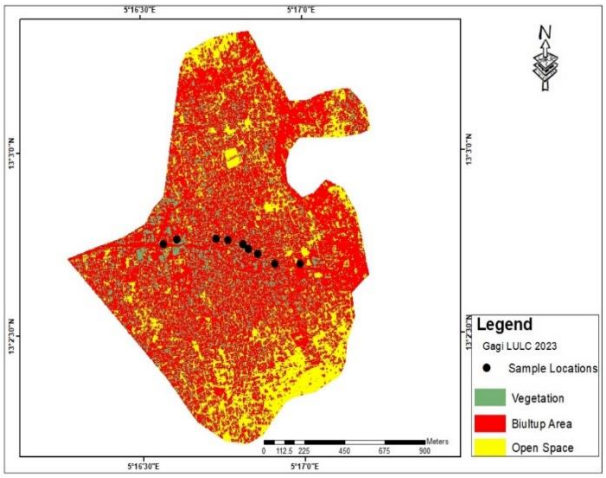

Figure 2(c): LULCC for Gagi (2023)

The LULC types and their percentage changes between the study periods were identified and presented (Tables 4 and 5). The study observed changes in the Nakasari area, where vegetation drastically reduced from 17.48% in 2000 to 12.01% in 2010 and 6.38% in 2023, respectively. Built-up changes from 20.51% to 45.95% in 2000 and 38.67% in 2023, respectively. In the Gagi area, vegetation changes from 25.24%,14.27% to 9.09% in 2000, 2010 and 2023, respectively. Build-up changes from 58.25% to 61.94% to 33.22% in 2000, 2010, and 2023, respectively.

Table 4: LULC Types and Percentage Changes for Nakasari (2000 -2023)

LULC Types	LULC 2000		LULC 2010		LULC 2023	
	Area (ha)	Area (%)	Area (ha)	Area (%)	Area (ha)	Area (%)
Vegetation	35.24	17.48	24.22	12.01	12.86	6.38
Built up	41.34	20.51	92.66	45.95	77.97	38.67
Bare land	8.71	4.32	52.48	26.03	32.06	15.90
Agricultural Land	116.31	57.69	32.28	16.01	78.73	39.05
Total	**201.60**	**100**	**201.60**	**100**	**201.60**	**100**

Table 4: LULC Types and Percentage Changes for Gagi (2000 -2023)

LULC Types	LULC 2000		LULC 2010		LULC 2023	
	Area (ha)	Area (%)	Area (ha)	Area (%)	Area (ha)	Area (%)
Vegetation	49.56	25.24	28.03	14.27	17.85	9.09
Built up	114.39	58.25	121.64	61.94	65.24	33.22
Open Space	32.43	16.51	46.71	23.79	113.29	57.69
Total	**196.38**	**100**	**196.38**	**100**	**196.38**	**100**

From the trend observed in LULC changes,, there was a decline in vegetation due to rapid population growth, leading to changes in the LULC pattern in the metropolis. These changes have a profound impact on the vegetation and also on the sequestration potential of trees in the

metropolis, which serves as a defence mechanism against climate change. It is in line with the observations by Abudu *et al*. (2019) and Jianzhu and Maduako (2018) that rapid population growth and LULC changes are some of the significant challenges of urban areas in developing countries with a profound impact on the vegetation and other valuable habitats.

As observed from the overall results, changes in vegetation reduced the carbon sequestration potential of trees in the study areas. However, to overcome such challenges, more trees should be incorporated into urban areas during these expansions to increase the carbon sequestration potential of TOF in the study area.

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ETHNOBOTANICAL INSIGHTS INTO NON-TIMBER FOREST PRODUCTS IN OJU LGA BENUE STATE: A PATHWAY TO FOREST SUSTAINABILITY AND COMMUNITY LIVELIHOODS

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Abstract
Non-Timber Forest Products (NTFPs) are integral to the livelihoods, health, and cultural heritage of forest-dependent communities, while also making significant contributions to forest conservation and biodiversity. This study presents ethnobotanical insights into NTFPs in the Oju Local Government Area of Benue State, Nigeria. Using a cross-sectional, mixed-method design, data were gathered through structured questionnaires, semi-structured interviews, and direct field observations involving 174 respondents across eleven council wards. The study documented 102 NTFP species spanning 49 botanical families, with Fabaceae, Euphorbiaceae, and Anacardiaceae being the most represented. Ethnobotanical indices, such as Relative Frequency of Citation (RFC) and Use Value (UV), were used to assess the significance of species. Irvingia gabonensis, Vitellaria paradoxa, and Garcinia kola were among the most valued species. Medicinal and edible uses dominated local applications, accounting for 38% and 32% of use cases, respectively. The findings highlight the critical role of women and youth in NTFP collection and knowledge preservation. Key threats to NTFP sustainability include deforestation, unsustainable harvesting, and the erosion of traditional ecological knowledge. The study accentuates the necessity of community-based conservation strategies and policy integration to enhance the sustainable management of NTFPs.

Keywords: Non-Timber Forest Products (NTFPs), Ethnobotany, Forest Sustainability, Indigenous Knowledge, Rural Livelihoods, Oju LGA, Benue State

INTRODUCTION

Forests are vital ecosystems that provide a multitude of goods and services essential for human well-being, biodiversity conservation, and climate regulation. (Brockerhoff *et al*., 2017). Non-Timber Forest Products (NTFPs) represent a vast and diverse array of biological resources harvested from forests, woodlands, and trees outside forests, excluding timber (Asamoah *et al.,* 2024). This category encompasses a wide range of products, including fruits, nuts, seeds, leaves, medicinal plants, bushmeat, insects, fungi, resins, fibres, and honey (Akanni, 2013). These resources play critical ecological roles within forest ecosystems, contributing to biodiversity and ecosystem health (Shikov *et al*., 2017). Furthermore, they provide indispensable contributions to the livelihoods, food security, healthcare, and cultural practices of communities residing in and around forested areas, often serving as crucial safety nets during periods of economic vulnerability or environmental change (Shackleton *et al*., 2011). The global significance of NTFPs for millions of people, particularly in developing regions, as sources of food, income, and medicine,, is widely acknowledged (Shackleton and De Vos, 2022).

Nigeria, a nation rich in biodiversity and varied agroecological zones, possesses a substantial wealth of NTFPs. These resources are deeply embedded in the socio-cultural and economic fabric of numerous communities across the country, significantly contributing to household economies, traditional knowledge systems, and local healthcare practices (Suleiman *et al*., 2017). The considerable income generated from

NTFP collection and trade highlights their role in poverty alleviation and livelihood diversification for rural populations (Arifalo, 2022). However, despite their evident importance, a notable gap remains in the comprehensive and systematic documentation of NTFP diversity, their ecological distribution, and the associated traditional knowledge concerning their sustainable harvesting and utilisation, particularly at localised levels within specific regions of the country (Okunlola *et al*., 2023). This lack of detailed, area-specific information impedes effective conservation strategies, sustainable management planning, and the full realization of NTFPs' potential to contribute to local and national development.

Benue State, located in the Middle Belt region of Nigeria, is endowed with significant forest resources that are known to harbor a variety of NTFPs. Local communities within the state have a long-standing history of utilizing these products for subsistence, traditional medicine, and trade (Min *et al*., 2024). However, detailed ethnobotanical studies systematically documenting the specific NTFPs available, their precise ecological distribution, and the intricate traditional knowledge surrounding their diverse uses are still limited across many parts of the state. This knowledge deficit is particularly apparent in areas like Oju Local Government Area, hindering informed decision-making regarding forest resource management, biodiversity conservation, and the sustainable development of NTFP-based livelihoods within this specific region. Therefore, a systematic investigation is crucial to document the floristic diversity and ethnobotanical uses of NTFPs within Benue State, with a particular focus on addressing the knowledge gap in Oju Local Government Area.

This study conducts a floristic and ethnobotanical survey of NTFPs in Oju LGA, aiming to document the variety of plant and animal-based NTFPs utilized by local communities, elucidate their usage patterns, and assess their contributions to community livelihoods and forest sustainability.

METHODOLOGY

Study Area

Oju Local Government Area of Benue State is located within the Southern Guinea Savannah zone. It lies between Longitude 8°25’0” and 8°41’67’’E, and Latitude 6°51 0” and 6°85’0’’ N. It borders Obi and Gwer East in the North, Konshisha and Yala in the East, Izzi and Ebonyi in the South, and Ado in the West.

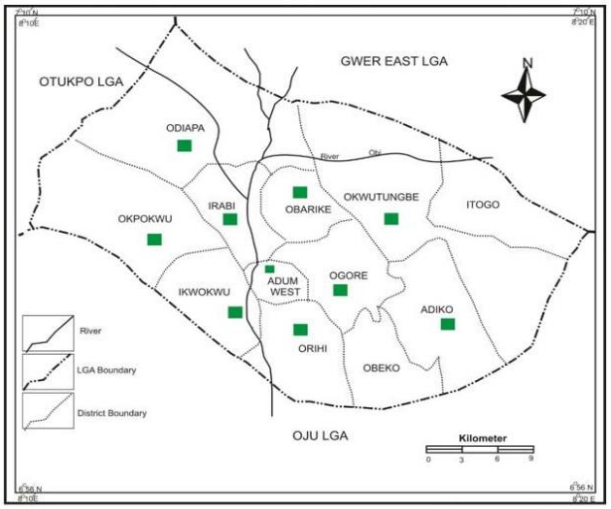

Figure 1: Map of Obi Local Government Area

Source: Ministy of Lands and Survey Makurdi

Climate

Oju Local Government Area is characterized by a Tropical Savanna Climate (Aw) with two distinct seasons, a wet season from April to October and a dry season from November to March; it receives a mean annual rainfall of between 1200mm and 1500mm, with the rainy season running from late March to early November, seeing the most precipitation in September (average 209 mm) and the least in December (average 2 mm), while experiencing a mean annual temperature of 30°C, with temperatures usually varying from 63°F to 89°F and seldom below 57°F or above 93°F, and relative humidity between 60% and 80% during the wet season decreasing in the early dry months. (Ikyaagba *et al*., 2019).

Study Design

A mixed-method cross-sectional research design was employed, combining quantitative household surveys with qualitative ethnobotanical interviews. This approach enabled both broad demographic coverage and in-depth documentation of traditional ecological knowledge relating to Non-Timber Forest Products (NTFPs).

Sampling Procedure

Oju Local Government Area (LGA) comprises eleven council wards. A multi-stage purposive sampling technique was used. First, three wards (representing approximately 30% of the total) were selected based on their recognized ecological richness and historical reliance on NTFPs (Abu, 2011).

From the selected wards, household data were obtained from local administrative records, which listed a total of 582 households. Using Taro Yamane's (1967) formula with a 5% margin of error, a sample size of 174 respondents was derived. The sample was proportionally distributed across the three wards to ensure representativeness.

Taro -Yamanes (1967) Method of Determining Sample Size

$$\mathbf{n}=\frac{N}{1+N(e)2}$$

…….. Equation (i)

Where:

N = Population,

1= constant,

e = tolerable error or limit of precision,

n = sample size

$$\mathbf{nh}=\frac{n \times Nh}{N}$$

……. Equation (ii)

Where:

nh = Number of households,

Nh = Population of households in a council ward

n = Sample size for the study.

N = Total household population

A total sample size of 174 respondents was derived for the study using the formula above, based on the total household population in Oju LGA. The sample size was proportionally distributed among the selected council wards.

Key informants, including herbalists, elders, hunters, NTFP traders, and community leaders, were selected using snowball sampling. Initial informants were identified with the help of community heads, and earlier participants referred subsequent respondents until thematic saturation was achieved.

Data Collection Methods

Structured questionnaires were administered to the 174 selected households to collect data on socio-economic characteristics (age, gender, occupation), frequency and diversity of NTFP use, economic dependence on NTFPs, gender and age-related roles in NTFP collection and use.

A semi-structured ethnobotanical questionnaire was administered to key informants to document Local names and uses of plant- and animal-based NTFPs, Harvesting techniques and tools, seasonal availability, conservation practices, threats, and cultural and medicinal significance. During field visits, NTFPs were identified and documented in situ in both cultivated and wild habitats. Plant and animal specimens were collected and catalogued using standard botanical protocols, including the use of field guides and herbarium verification for species confirmation.

Data Analysis

Data were analyzed using descriptive statistics (frequencies, percentages) and ethnobotanical indices.

RESULTS

Socio-Economic Characteristics of Respondents in Oju LGA

The socio-economic profile of respondents involved in the collection, use, and trade of Non-Timber Forest Products (NTFPs) is presented in Table 1. The majority of respondents were male (63.2%). The most common age group was 31–45 years (39.1%). Most respondents were married (75.9%), and the majority had attained secondary education (35.1%). In terms of occupation, farming (52.3%) was the dominant livelihood activity. The primary source of income for most respondents was from Non-Timber Forest Product (NTFP)-based activities (45.4%).

Table 1. Socio-Economic Characteristics of Respondents in Oju LGA

Variable	Category	Frequency (n)	Percentage (%)
Gender	**Male**	**110**	**63.2**
	Female	**64**	**36.8**
Age	**18–30 years**	**38**	**21.8**
	31–45 years	**68**	**39.1**
	46–60 years	**45**	**25.9**
	61 years and above	**23**	**13.2**
Marital Status	**Married**	**132**	**75.9**
	Single	**23**	**13.2**
	Widowed/Divorced	**19**	**10.9**
Education Level	**No formal education**	**38**	**21.8**
	Primary education	**53**	**30.5**
	Secondary education	**61**	**35.1**
	Tertiary education	**23**	**13.2**
Occupation	**Farmer**	**91**	**52.3**
	Herbalist	**19**	**10.9**
	Hunter	**15**	**8.6**
	Trader	**23**	**13.2**
	Community Leader/Civil Servant	**26**	**14.9**
Primary Income Source	**NTFP-based activities**	**79**	**45.4**

Variable	Category	Frequency (n)	Percentage (%)
	Farming	**57**	**32.8**
	Trading	**23**	**13.2**
	Others	**15**	**8.6**

Diversity and Ethnobotanical Use of Non-Timber Forest Products in Oju LGA

The diversity, sources, and ethnobotanical uses of Non-Timber Forest Products (NTFPs) identified in Oju Local Government Area is presented in Table 2. It categorises various NTFPs based on their biological classification and outlines their scientific and local names, the specific plant or animal parts used, their primary uses, seasonal availability, and associated conservation practices. The table illustrates the rich bio-cultural knowledge within the community and highlights the multifunctional role that NTFPs play in local subsistence, healthcare, the economy, and cultural traditions. Additionally, it reflects community-based conservation efforts aimed at promoting sustainable harvesting and protecting these valuable forest resources.

Table 2: Diversity and Ethnobotanical Use of Non-Timber Forest Products in Oju LGA

Class	**NTFPs *(Scientific / Local Name***	**Sources**	**Part Used**	**Uses**	**Seasonality**	**Conservation Practices**
Bushmeat	*Thryonomys swinderianus (Grasscutter), Helogale spp. (Guinea fowl), Python sebae*	Bushland	Whole	Food, Hide, Medicine, Drum	Dry season	Hunting limits, taboo species
Palm Products	*Borassus aethiopium (Adede)*	Palm groves	Leaves, Branches, Root	Weaving mats, chairs, and food	Year-round	Selective pruning
Edible Insects	*Bunaea alcinoe, Cirina forda, Termites*	Host trees	Whole	Food	Rainy season	Tree protection
Bush Mango	*Irvingia gabonensis (Ogbono)*	Forest	Seed (Endocarp)	Soup thickener	Rainy season	Community harvest rules
Fuelwood	*Prosopis africana, Lophira lanceolata*	Forest	Trunk	Cooking, Heating	Year-round	Rotational felling

Class	NTFPs *(Scientific / Local Name*	Sources	Part Used	Uses	Seasonality	Conservation Practices
Chewing Stick	*Carpobrotus spp.*	Bush	Stem	Oral hygiene	Year-round	Minimal
Drums	*Khaya senegalensis, Vitellaria paradoxa*	Forest	Trunk	Musical instruments	Year-round	Sacred species protection
Fodder	*Afzelia africana, Vitex doniana*	Trees	Branches	Livestock feed	Dry season	Coppicing, dry season use only
Soup Vegetables	*Gnetum africanum, Cissus populnea, Mushrooms*	Forest floor, shrubs	Leaves, whole	Soup	Rainy season	Regulated harvest
Oils	*Vitellaria paradoxa, Afzelia africana*	Seeds	Seeds	Cooking oil, skin care	Dry season	Seed tree retention
Fruits	*Ximenia americana, Strychnos spinosa*	Various trees	Fruit	Food	Rainy season	Selective collection
Honey	*Bee and Wasp Honey*	Hives in trees	Whole	Food, Medicine	Dry season	Bee-friendly harvesting
Medicinal Products	*Leaves, Roots, Bark, Animal parts*	Various plants & animals	Multiple parts	Treatment of ailments	Year-round	Knowledge held by elders
Craft Materials	*Prosopis africana, Paullinia pimata*	Forest	Trunk, Branches	Mortars, Pestles	Year-round	Replanting in fallow areas
Spices/Condiments	*Parkia biglobosa, Prosopis africana*	Forest trees	Seed	Soups, Medicine	Dry season	Controlled collection

DISCUSSION

The socio-economic profile of respondents in Oju LGA reveals a male-dominated (63.2%) and largely middle-aged population (31–45 years: 39.1%) actively engaged in forest-based livelihoods. While this aligns with prior studies (Gideon, 2018), who noted a male prevalence in NTFP collection. The study revealed that in Oju Local Government Area, customary land and forest access rights predominantly favour men, particularly in activities such as hunting and collecting firewood**.** In contrast, women were more actively involved in the gathering of fruits, vegetables, and medicinal herbs. It observed gender-based division of labour significantly influenced the reported diversity of Non-Timber Forest Products (NTFPs)**,** especially concerning animal-based products**,** which were found to be primarily sourced by male respondents.

The dominance of married respondents (75.9%) highlights the role of forest resources in household provisioning. Married individuals often support larger families, necessitating diversified income streams. The reliance on

NTFPs (45.4% as a primary income source), therefore, reflects a livelihood strategy grounded in necessity rather than preference, particularly where formal employment opportunities are scarce.

The educational background limited primarily to primary (30.5%) and secondary education (35.1%), shapes both the depth and transmission of ethnobotanical knowledge. Those with no formal education (21.8%) are often repositories of traditional ecological knowledge, which plays a vital role in sustainable harvesting and species identification (Haq *et al*., 2023) Conversely, limited formal education may restrict access to external markets, advanced processing techniques, and sustainable management training, potentially leading to unsustainable exploitation due to a lack of alternatives.

Occupation also significantly influences NTFP dependency. While farming remains dominant (52.3%), other roles, such as those of herbalists, traders, and hunters, point to a diversified economy built around forest products. In the study conducted in Oju Local Government Area, it was observed that farmers integrate Non-Timber Forest Products (NTFPs) as supplementary income sources during off-seasons. This practice provides them with additional revenue streams, enhancing their livelihoods when agricultural activities are minimal. Similarly, traders and herbalists specialize in value chains involving medicinal plants and animal parts, engaging in activities such as sourcing, processing, and selling these products. This specialization not only contributes to their economic well-being but also plays a significant role in the local economy by sustaining the demand and supply of traditional medicinal products.

These findings align with a study by Adewumi et al. (2020), which revealed that the medicinal plant supply chain is predominantly informal and comprises gatherers, farmers, herbal medicine producers, and final consumers. Farmers and gatherers were identified as primary suppliers,

The intersection of occupation and NTFP dependence is key to understanding the scale and intensity of resource extraction.

The study documented a rich diversity of NTFPs spanning 15 distinct categories, including bushmeat, edible insects, fruits, vegetables, oils, medicinal products, and craft materials. It reflects not only ecological richness but also the cultural entrenchment of forest product use in Oju LGA.

Animal-Based Products such as bushmeat (Grasscutter, giant rat, python) and edible insects (*Bunaea populnea*, termites) are integral to local diets and medicinal practices; their usage illustrates both nutritional reliance and traditional therapeutic systems, a finding consistent with Bennett and Robinson (2000). Ethnobotanical interviews revealed that python fat is believed to treat arthritis, while grasscutter bile is used for malaria. It highlights the embeddedness of fauna in health systems where access to biomedical care is limited.

Plant-Based Products, including palm products, soup vegetables (*Gnetum africanum, Cissus populnea*), and medicinal herbs, show multifunctional usage patterns. It was revealed that these plants meet dietary, spiritual, and economic needs, with local names and uses varying across age groups and ethnic sub-clusters within Oju. A unique observation during the study was the use of *Borassus aethiopium* roots for toothache an insight passed from elders to youths through oral tradition. This intergenerational transmission of knowledge is a critical yet underappreciated component of sustainable NTFP management.

Fuelwood and charcoal extraction, while vital for energy, raise ecological concerns. Interviews indicated increasing scarcity of *Prosopis africana* and *Burkea africana*, suggesting signs of overharvesting. It calls for urgent ecological monitoring and the development of alternative energy solutions to reduce pressure on forest stands.

Despite the analytical separation in presentation, the socio-economic characteristics of respondents are intricately linked to patterns of

NTFP use. Younger respondents (18–30 years) reportedly focus more on marketable products, such as honey, fruit, and firewood, for quick income, while older adults (46+) are custodians of medicinal plant knowledge. Those with secondary or tertiary education demonstrate a better awareness of sustainable harvesting, although they are fewer in number. Formal training workshops or community education tailored to less-educated groups could significantly enhance resource conservation.

Herbalists and traders tend to specialise in specific product chains, such as herbs, oils, and animal parts, suggesting opportunities for targeted value addition and supply chain support. Farmers primarily use forest products as safety nets during lean periods.

This integrative view suggests that conservation strategies should be tailored to the socio-economic context of the community, rather than treating forest users as a homogeneous group.

Despite the wealth of NTFPs documented, the discussion must be tethered more strongly to the sustainability dimension, especially given the study's framing as a pathway to forest sustainability. Several products, including fuelwood species (Lophira lanceolata and Khaya senegalensis) and medicinal plants, are showing signs of overuse. Traditional beliefs in the inexhaustibility of forest resources may lead to unsustainable practices, particularly as demand increases with population pressure.

There is little evidence of structured replanting or fallow management systems among users. Yet, traditional ecological knowledge encompasses practices such as selective harvesting and rotational gathering, which, if revitalised, could form the backbone of community-based forest management. Gendered knowledge systems, for example, provide differentiated but complementary insights into plant regeneration and seasonal availability.

The discussion notes that the proportion of respondents relying on NTFPs as their primary source of income (45.4%) is notably higher compared to other regions in Nigeria. For instance, a study around Falgore Game Reserve in Kano State found that income from NTFPs accounts for 20–60% of the total income of most (68%) of the sampled household (Suleiman *et al*., 2017) This comparison highlights the unique ecological and cultural context of Oju LGA, where limited formal employment and deeply rooted cultural beliefs contribute to a higher dependence on NTFPs.

The discussion provides actionable recommendations, including species-specific conservation efforts, sustainable harvesting training tailored to literacy levels, value chain support, gender-responsive policies, and the integration of local knowledge into forest management.

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FUELWOOD AS A CHEAP COOKING ENERGY SOURCE: BENEFITS AND LIMITATIONS

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ABSTRACT

This review examines the environmental and public health impacts of developing nations' prolonged reliance on fuelwood and charcoal as their primary home energy sources. It emphasizes how conventional techniques for producing charcoal lead to soil erosion, water pollution, deforestation, and forest degradation. When biomass fuels are burned, harmful pollutants are released, including polycyclic aromatic hydrocarbons (PAHs) and fine particulate matter ($PM_{2.5}$), which are linked to cancer, heart disease, and severe respiratory ailments. Ineffective methods of use and manufacturing significantly increase greenhouse gas emissions and exacerbate environmental degradation. The review assesses how sustainable forest management techniques, including Forest Landscape Restoration (FLR) and the REDD+ framework, as well as enhanced kiln technologies, might lessen these adverse effects.

It underscores the urgency for robust policy interventions, greater investment in clean cooking technologies, and expanded research into sustainable, low-emission energy alternatives to promote equitable and environmentally sound energy access. It emphasizes the urgent need for robust policy interventions, increased investment in clean cooking technologies, and expanded research into sustainable, low-emission energy options to promote equitable and environmentally sound energy availability.

Keywords: Emission, Charcoal, Fuelwood, Deforestation and Sustainable

Introduction

Access to energy is a crucial component of development, as it significantly influences a household's livelihood status and has a ripple effect on its economic situation. However, approximately 3.0 billion people worldwide do not have access to clean cooking energy, 1.3 billion do not have access to electricity, and 2.7 billion rely on dirty energy sources such as firewood and biomass for cooking and heating, which have negative consequences for human health and the natural environment (Kitole *et al*., 2023).

The estimated 2.4 billion people worldwide who relied on conventional biomass as a source of cooking and heating fuel in 2002 are predicted to rise to 2.6 billion by 2030, representing an 8% increase. For their culinary needs, more than half of urban households in sub-Saharan Africa rely on firewood, charcoal, or wood waste (Mainimo *et al*., 2022). In many developing countries, fuelwood is the primary source of energy, accounting for 60-80% of overall wood

consumption, particularly in rural regions. It can also account for 50% to 90% of home energy (Singh *et al*., 2021; Sintayehu Eshetu, 2025). The incomplete combustion of biomass in traditional, inefficient cooking systems can have significant consequences for human health, the environment, society, and the climate system (Singh *et al*., 2021).

According to research, adopting cleaner and better cookstoves can: a) reduce the use of fuelwood that is not sustainably harvested, which will benefit forest resources and slow down climate change; b) significantly improve household air quality and human health by reducing smoke; and c) offer social benefits like time savings from less fuelwood collection (Singh *et al*., 2021).

Fuelwood remains a primary energy source for cooking in many developing countries, offering a cost-effective solution for households lacking access to modern energy sources. However, the reliance on fuelwood presents significant environmental, health, and safety challenges. This review examines the multifaceted implications of fuelwood use, with a focus on charcoal production, deforestation, soil degradation, health risks, water pollution, safety concerns, and agricultural impacts. The sources for this review were identified through targeted searches in Google Scholar, Scopus, PubMed, and official databases from the FAO, WHO, and the World Bank, using terms such as "fuelwood," "biomass energy," "indoor air pollution," and "rural cooking fuels." Relevant studies addressing economic, environmental, health, and policy aspects were included, and data were synthesized thematically to capture the advantages and limitations of fuelwood as a cooking energy source. This review is based on peer-reviewed articles, institutional reports, and grey literature published between 2010 and 2025.

Charcoal Production: Methods and Advances Focusing on Sustainability

Charcoal is used in many different fields and applications, with cooking and heating being the two main uses of charcoal. Because of its lengthy burn time, strong heat production, and capacity to give food a smoky flavour, it is preferred for grilling and barbecue (Mencarelli *et al*., 2023) According to Nonsawang *et al*. (2024), charcoal briquettes manufactured from agricultural waste were discovered to have encouraging outcomes as a clean and effective cooking fuel, lowering emissions and enhancing the quality of indoor air. Due to its high carbon content and low impurities, charcoal is also frequently used in metallurgical processes, such as the production of iron and steel. Charcoal also finds use in air and water filtration systems. Activated charcoal is a valuable tool for water treatment, as it has been demonstrated to effectively remove impurities and pollutants from water sources (Getahun *et al*., 2024).

The world's primary renewable fuel, charcoal, has been produced and consumed since the dawn of civilization. Discussions concerning the use of charcoal are common, as it is believed that one-third of the world's population currently relies on biomass as their primary energy source. Through various production methods and technological advancements, this fuel has been produced for decades and is now available in nearly every home, primarily in developing nations (Pereira *et al*., 2023).

The methods used to produce charcoal vary significantly, ranging from simple and traditional to sophisticated and effective procedures. Along with the production's impact on the environment, the effectiveness of these techniques has significant implications for the quantity and quality of charcoal produced. Although they are widely utilised in many areas, traditional techniques such as pit kilns and earth mound kilns are notorious for their high pollution outputs and poor efficiency. Conversely, more effective substitutes that provide greater charcoal yields and a lower environmental impact include pyrolysis technologies and retorts (Getahun *et al*., 2024). Earth mound kilns and other conventional ways

of producing charcoal are popular because they are inexpensive and straightforward, but they have significant adverse effects on the environment, excessive wood consumption, and poor conversion efficiency. Modern, upgraded kilns, such as metal, retort, and casamance kilns, on the other hand, offer far higher efficiency, higher charcoal outputs, lower emissions, and better financial returns for manufacturers. These developments support sustainable resource management and climate mitigation in addition to reducing production costs (Tazebew *et al*., 2023).

A study in Kenya by Njenga *et al*. (2023) focused on strengthening the capability for sustainable charcoal production, including `improving the traditional earth mound kiln (TEK) that is utilized by 99% of charcoal farmers in Kenya. In the study, trim stems and branches of the invasive *Prosopis juliflora* were employed and generated fine charcoal with 28 kJ/g, which will conserve trees. The study's findings revealed that the improved earth mound kiln (IEK) decreased emissions of carbon monoxide, carbon dioxide, and hydrocarbons by 40%, 49%, and 44%, respectively, and increased charcoal production by 49% per mass of sun-dried wood fed into the kiln. Additionally, in TEK and IEK, the net charcoal yield by mass of dry wood was 26.4% and 28.4%, respectively. They concluded that communication and capacity building on sustainable charcoal production benefit people and the environment.

Tazebew *et al*. (2023) conducted a study in Ethiopia to assess the efficiency and environmental impact of charcoal production from small-scale Acacia decurrens plantations, using both traditional Earth mound kilns and improved kiln technologies, including the Green Mad Retort, MRV Portable Steel, and Casamance kilns. The MRV steel kiln achieved the highest conversion efficiency (41.57%), significantly outperforming the Earth mound kilns (24%) ($P \leq 0.001$). Improved kilns enhanced charcoal yield by 41–72%, substantially increased income per hectare (up to 284,824.4 ETB), and significantly reduced harmful gas emissions — including reductions in CO_2 (46–57.9%), CO (29.4–56.6%), NOx (56.6–86.2%), and CH_4 (35.7–57%). The study's findings underscore the need to adopt improved kiln technologies to enhance sustainability, economic returns, and environmental health in charcoal-producing regions.

According to a study by Adeniji *et al*. (2022) conducted in Borgu Local Government Area, Niger State, Nigeria, 82% of producers use the traditional earth mound kiln as their primary technique for producing charcoal. This inefficient method significantly worsens the environment because it consumes a large amount of wood and generates substantial emissions. Deforestation, biodiversity loss, and soil degradation are exacerbated by the dependence on open-access forests and the favored usage of species such as *Prosopis africana*. These results highlight the need to adopt more sustainable options and the environmental implications of conventional charcoal production processes.

Deforestation For Fuel Wood Production

The use of traditional wood fuels contributes significantly to forest degradation, particularly in Africa, and accelerates climate change, even if it is not a frequent significant cause of deforestation. Deforestation affects weather patterns, water cycles, and biodiversity, in addition to contributing to carbon emissions. Global Forest Watch estimates that in 2022, the world lost 11.1 million hectares of tropical forest, resulting in the release of billions of tons of CO2 into the atmosphere. Thus, deforestation ranks second only to the burning of fossil fuels as a major contributor to climate change (Obani *et al*., 2025). A combination of non-renewable wood fuel harvesting, charcoal manufacture, and incomplete combustion products, such as carbon monoxide, methane, black carbon, and fine particulate matter, contributes to the climatic impact (Quinn *et al*., 2018).

When solid fuels, such as coal and wood, are burned, toxic pollutants like carbon monoxide, nitrogen oxides, and particulate matter are released. These pollutants can lead to respiratory issues as well as other health issues. Approximately 4 million premature deaths occur annually due to exposure to these

pollutants from indoor cooking fires, primarily in developing nations, according to the World Health Organisation (WHO, 2024). In addition to having a significant impact on people's health, this also affects these nations' economic growth because sick individuals are unable to contribute to the economy fully. Moreover, cooking with solid fuels contributes to climate change and deforestation. Deforestation leads to a decline in biodiversity, which can impact residents' livelihoods and food security (Clean Cooking Alliance, 2022).

Additionally, cooking with solid fuels releases greenhouse gases that cause climate change (Kitole *et al*., 2023). Chidumayo and Gumbo (2013) reported that, although charcoal has the potential to help reduce poverty and promote environmental sustainability, it accounts for less than 7% of deforestation in the tropics, and the most common outcome of its manufacturing is forest degradation. However, fast forest regrowth is possible in the majority of charcoal regions, if there is improvement in the legitimacy and efficient execution of charcoal policies. Van Dam (2017) reported that worldwide, it is estimated that 50% of the wood harvested from forests is used for fuel, with roughly 17% of that amount being turned into charcoal. For instance, between 2015 and 2020, deforestation rates in Nigeria were 163,000 hectares per per year, with the manufacturing of charcoal playing a significant role (Isese, 2019; Sedano *et al.*, 2019).

According to a study by Ablo *et al*. (2022) on charcoal production in Ghana, charcoal manufacturing is crucial for meeting household energy demands. With uneven benefit streams, charcoal alters local economies and sustains livelihoods. The manufacturing of charcoal has varying degrees of responsibility for the loss of flora and ecological resilience. In regions where local charcoal manufacturers consistently produce, the amount of vegetation loss is most significant.

Rotowa *et al*. (2019) reported that a large portion of Nigeria's population, especially in rural regions, continues to rely on fuelwood and charcoal as their principal energy sources. Nigeria consumes the majority of its charcoal internally and exports tiny, despite being the continent's largest producer and the second-largest producer worldwide. Deforestation and desertification are significantly exacerbated by this high demand, which is largely met through conventional production techniques that utilise forest trees. Continued use of charcoal poses significant environmental risks in the absence of sustainable forest management and enhanced supply systems, such as tree planting and participatory forest governance.

According to a longitudinal study evaluating charcoal production trends in Nigeria from 1961 to 2021 by Bolaji *et al*. (2024), population growth, industrial demand, and rising fuel prices all contributed to a sharp rise in output volume of more than 515%. Deforestation, greenhouse gas emissions, and biodiversity loss have all been further exacerbated by the extensive use of traditional production techniques, such as earth mound kilns. The demand for charcoal is expected to continue increasing until 2050, underscoring the pressing need for cleaner manufacturing methods and sustainable forest management.

Soil Degradation via Erosion and Nutrient Depletion

Forest degradation is caused by population increase, land-use change, and unsustainable practices such as shifting agriculture, resulting in severe nutrient depletion in terrestrial ecosystems. The elimination of plants and topsoil due to deforestation and poor forest management disrupts natural nutrient cycling, resulting in lower soil fertility, increased erosion, and long-term declines in ecosystem productivity (Mayer *et al*., 2020). These changes degrade ecological services, impede forest regeneration, and have a severe impact on agriculture and local livelihoods. Restoration initiatives, such as REDD+ and forest landscape restoration (FLR), aim to mitigate these consequences by enhancing nutrient retention through natural regeneration, agroforestry, and erosion control measures (Kumar *et al*., 2022).

Charcoal manufacturing for urban energy in Sub-Saharan Africa is a significant yet underreported cause of forest degradation. A study conducted in central Mozambique by Sedano *et al*. (2016), utilising high-resolution satellite imagery, discovered that charcoal-driven degradation occurs independently of agricultural deforestation while having a similar impact on forest cover and carbon emissions. Mapping kiln locations revealed the spatial and temporal scales of degradation, which, when paired with field data, revealed significant aboveground biomass loss and emissions. Linking urban charcoal demand to forest degradation is a viable technique for reducing uncertainty in carbon and land cover assessments throughout the region (Sedano *et al*., 2016).

A study by Emeodilichi (2018) on charcoal production processes in Kaduna, Nigeria, showed that to create charcoal, wood must be carbonised in low-oxygen conditions, often in metal silos or conventional earth kilns. Only around 25% of the original wood mass is retained during this process, which is largely dependent on unsustainable tree harvesting, despite producing carbon-rich fuel for residential and commercial use. In Nigeria, severe deforestation has resulted from the widespread manufacture of charcoal without regeneration. It accelerates soil deterioration, contributing to climate change and the accumulation of carbon dioxide in the atmosphere. Removing trees damages organic matter, exposes soil to erosion, and disrupts nutrient cycling, particularly in tropical areas where forest cover is crucial for maintaining soil fertility. As a result, agricultural productivity gradually declines, and long-term soil degradation occurs.

Deforestation and Carbon Emissions

Deforestation for agricultural purposes emits approximately 2.6 billion tons of CO2 each year, accounting for around 6.5% of global emissions. The majority of deforestation happens in the tropics. Is this deforestation caused by internal demand in these countries or foreign trade? Demand for food items in their native country accounts for two-thirds of deforestation emissions, with international trade accounting for the other third. Closer monitoring of international supply chains may thus offset part of this deforestation, but until local markets adopt stronger policies, large-scale deforestation will persist (Hannah Ritchie, 2021).

Charcoal use has been high, and demand is likely to rise more in the coming decades, particularly in Sub-Saharan Africa. According to some preliminary studies, among regularly used cooking fuels, charcoal may be the most greenhouse gas-intensive. Despite the importance of wood fuel in many nations, few have explicitly included policies to minimise emissions from its production and use.

Sonter *et al*. (2015) found that replacing coal with charcoal in the steel sector in Brazil led to increased deforestation due to shortages of plantation wood. Native forest charcoal emits up to 9x more CO_2 per tonne of steel compared to coal. CO_2 emissions doubled (91 to 182 Mt) between 2000 and 2007, despite a decrease in coal consumption. A more recent study discovered that the use of fuelwood in a particular location led to about 974,000 kg of CO_2 emissions per year (Sintayehu Eshetu *et al*., 2025). Avoiding native forest charcoal might have saved 79% of these emissions, but increasing plantations raises socioeconomic and deforestation hazards (Sonter *et al*., 2015).

Health Implications of Polycyclic Aromatic Hydrocarbons (PAHs)

Charcoal production and use are associated with a range of adverse health outcomes, including respiratory diseases such as asthma, tuberculosis, and chronic obstructive pulmonary disease, as well as cancer, DNA damage, carbon monoxide poisoning, cardiovascular and neurological disorders, physical injuries, and increased mortality (Idowu *et al*., 2023).

PAHs are dangerous chemical substances found throughout the environment. PAHs pose considerable health hazards such as increased risk of cancer, cardiovascular disease,

respiratory problems, and developmental issues. Certain PAHs are known carcinogens, mutagens, teratogens, and cause infertility. PAHs are particularly resistant to degradation due to their hydrophobic, thermostable, and complex ring structures. However, remediation approaches, including bioremediation, have been investigated to remove PAHs from the environment (Patel *et al*., 2020; Venkatraman *et al*., 2024).

Acute PAH exposure can result in eye irritation, nausea, vomiting, and diarrhoea, whilst chronic exposure has been linked to cancer, cardiovascular illness, respiratory problems, and reproductive abnormalities. Although most research is based on animal studies, the findings suggest that PAHs may cause significant harm to humans through processes such as DNA damage (Feng *et al*., 2024).

A systematic review by Bede-Ojimadu and Orisakwe (2020) reported that personal exposure to wood smoke in sub-Saharan Africa frequently exceeds WHO air quality guidelines, with $PM_{2.5}$ levels ranging from 26.3 to 1574 μg/m³ and CO levels up to 22 ppm. Women and individuals involved in domestic and occupational wood fuel use (e.g., cooking, fish drying, charcoal production) were most affected. Exposure was consistently associated with respiratory illnesses, impaired lung function, and other adverse outcomes, including increased blood pressure, low birth weight, oesophageal cancer, sick building syndrome, and under-five mortality. Table 1 shows the key Polycyclic Aromatic Hydrocarbons (PAHs) from wood smoke and their health effects on humans.

Table 1: **Key Polycyclic Aromatic Hydrocarbons (PAHs) from Wood Smoke and Their Health Effects**

PAH Compound	Primary Source in Wood Smoke	Human Health Effects
Benzo[α-]pyrene (BaP)	Incomplete combustion of wood	Potent carcinogen; linked to lung and skin cancers; causes DNA damage and oxidative stress
Naphthalene	Low-temperature wood burning	Respiratory irritation; hemolytic anaemia; potential carcinogen
Phenanthrene	Volatilized from burning organic matter	Eye and skin irritation; potential immunotoxic effects
Fluoranthene	Released during the combustion of biomass	Possible mutagen; causes skin and eye irritation
Pyrene	Common product of wood pyrolysis	Skin irritation, suspected liver toxicity, associated with oxidative stress

Source: (Samburova *et al*., 2016; Sengupta *et al*., 2023)

Water Pollution and Toxicity to Edible Plants

Water pollution is another issue related to charcoal production. Runoff from charcoal production facilities may contain toxic

chemicals and contaminants, such as trace metals, carbon monoxide (CO), carbon dioxide (CO2), particulate matter (PM), polycyclic aromatic hydrocarbons (PAHs), volatile organic compounds (VOCs), and other small pollutants (Mencarelli *et al*., 2023), contaminating surrounding water supplies. The ash and chemicals from the production process can enter rivers, streams, and other bodies of water, impacting water quality and endangering aquatic ecosystems, wildlife, and local communities that rely on these water sources for drinking water and other needs (Oladimeji *et al*., 2024)

To reduce air and water pollution from charcoal production, it is crucial to implement effective pollution control measures, such as the use of technologies like smokeless kilns or biochar production methods, which reduce emissions while improving air quality. Proper manufacturing site management, including ash and chemical containment, as well as the use of appropriate waste disposal techniques, can all help reduce water contamination (Vietnam Charcoal, 2023).

Table 2: **Impacts of Wood Smoke Pollutants on Aquatic Life and Water Quality**

Pollutant	**Pathway into Water**	**Impact on Water Quality**	**Effect on Aquatic Life**
Organic Gaseous Compounds (OGCs)	Atmospheric deposition, runoff containing volatile organics	Increases chemical oxygen demand (COD); forms toxic by-products (e.g., phenols, aldehydes)	Toxic to fish and invertebrates; bioaccumulation; endocrine disruption
Carbon Monoxide (CO)	Dissolution from atmospheric CO or waterlogged soils	Disrupts oxygen exchange in water; weakens redox balance	Reduces dissolved oxygen availability, indirectly stressing aquatic organisms
Nitrogen Oxides (NO_x)	Atmospheric deposition, acid rain	Leads to acidification and eutrophication; alters nitrogen cycle	Promotes algal blooms, depletes oxygen, and leads to fish kills; toxic to amphibians
Carbon Dioxide (CO_2)	Atmospheric absorption in water	Lowers pH (forms carbonic acid); affects buffering capacity	Alters aquatic respiration; impacts shell formation in mollusks and corals; contributes to ocean acidification

Source: (Shah *et al*., 2022; Raoelison *et al*., 2023; Mustafa *et al*., 2024).

Safety Regulations for Fuelwood Production

The Nigerian government should develop policies to reduce deforestation and promote the use of alternative energy sources. The government should monitor fuelwood consumption across regions to identify high-usage areas and target interventions accordingly. The regulatory agency in charge should also be staffed up and equipped with logistics (Rotimi *et al*., 2024).

Harvey and Guariguata (2020) propose that forest landscape restoration initiatives can help meet the ongoing demand for sustainable

fuelwood by implementing three complementary actions:

- improving the sustainability of fuelwood production through tree planting, natural regeneration, and other restoration activities;
- Reducing fuelwood demand through the use of more efficient stoves and kilns; and
- Reducing unsustainable fuelwood harvesting from native forests."

Conclusions and Recommendation

This review of the literature highlights the significant role of fuelwood as a primary source of energy for households, while also contributing to serious environmental and public health concerns. In many impoverished nations, fuelwood remains an inexpensive cooking fuel, but its extensive use is associated with deforestation, soil nutrient loss, air and water pollution, and exposure to hazardous pollutants, including as particulate matter and polycyclic aromatic hydrocarbons (PAHs). Charcoal's irresponsible production and use exacerbate these effects by increasing carbon emissions and accelerating the destruction of forests.

In response, various local and international initiatives are underway. To reduce reliance on biomass fuels, governments and non-governmental organisations have begun promoting clean cooking options, such as solar cookers, liquefied petroleum gas (LPG), and upgraded cookstoves. Initiatives backed by the Clean Cooking Alliance, the World Bank, and national renewable energy agencies emphasise access to cleaner technologies, infrastructure investment, and behavioural change. To repair damaged ecosystems and promote sustainable wood harvesting, reforestation and afforestation initiatives, community-based forest management, and carbon credit programs are also being implemented.

Significant gaps still exist, nevertheless, in the areas of long-term clean technology uptake, policy enforcement, and the incorporation of sustainable energy planning into rural development plans. To close these disparities and align regional practices with international environmental objectives, a comprehensive and inclusive policy framework is necessary. The creation and contextualization of cleaner cooking technology, scalable funding sources, and forest preservation strategies should be the top priorities of future studies. Securing a healthier and more resilient future will require striking a balance between environmental sustainability and energy access.

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ASSESSMENT OF FUELWOOD AND ITS BUSINESS PRACTICES IN LIMAWA COMMUNITY, KANO STATE, NIGERIA

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Abstract

This study assessed fuelwood handling in the Limawa community, Kano State, Nigeria. The specific objectives of the study were to identify the socio-economic characteristics of fuelwood handlers, determine the common tree species used for fuelwood, examine the business practices and constraints associated with fuelwood handling in the study area. A multi-stage sampling procedure was used to select 42 handlers, comprising wholesalers and harvesters, and data were obtained using a a well-structured questionnaire. The results showed that the wholesalers were experienced, middle-aged individuals, predominantly male and married. Their average age was 51, with more than 15 years of business experience, larger family size, and lower educational status. They faced challenges such as high transportation costs, poor road networks, and insecurity. Similarly, the harvesters were males and came from a married demographic with diverse educational backgrounds. They engaged in small to moderate-scale operations with 1-10 workers, harvesting various tree species, including *Anogeissus leiocarpus, Pterocarpus erinaceus, Parkia biglobosa, Tamarindus indica, Prosopis africana, Terminalia* species, *Eucalyptus camaldulensis,* and *Diospyros mespilliformis*. These species were often sourced from farmlands and natural environments, with some harvested from as far away as Bauchi, Gombe, and Sokoto States. This study offers a comprehensive understanding of the socio-economic context, business practices, and challenges faced by fuelwood handlers, underscoring the need for targeted interventions by stakeholders.

Keywords: Limawa, Fuelwood, Handlers, Harvesters, Marketers, Retailers, Constraints

Introduction

For a long time, forests have contributed directly and indirectly to rural household livelihoods through the generation of income and employment from the sale and exchange of gathered, unprocessed non-timber forest products, such as firewood (De Giusti *et al.,* 2019). Fuelwood is an encompassing term used to describe wood and wood pulp materials obtained from the branches, stems, roots and other parts of trees and shrubs, which is burnt directly to generate energy to be used for cooking and heating in household or industrial uses. Biomass energy is recognised as one of the largest energy sources, with fuelwood contributing to more than 10% of the total global energy consumption (Magembe and Makonda, 2016). It is primarily consumed by low- and middle-income households, as well as operators of small-scale industries and commercial enterprises, particularly in countries with developing economies. More than 80% of households in Nigeria and other developing countries rely on fuelwood for cooking, making it the most widely used energy source, largely due to its availability and affordability compared to other alternative sources of energy (Naibbi and Healey, 2015; Akeh *et al*., 2023). However, this overreliance came with a great cost to the forest cover and the environment as a whole. Previous studies have found that fuelwood consumption in the north and south western parts of Nigeria far exceeds sustainable production (Ekanade, 2018). The deficit is only made up from areas of surplus (pockets of localised vegetation in the other parts of the

country), which adds to the cost of the wood (Naibbi and Healey, 2013).

Fuelwood is not only used for self-consumption, but it also provides the local communities with a vital source of livelihood. Given the range of activities and the employment opportunities it generates, fuelwood extraction can also be described as a commercial activity (Naibbi, 2015). Traditionally, this practice was primarily carried out by rural communities, particularly those dwelling in the vicinity of the forest. They were responsible for the extraction, handling and the supply of fuelwood to other local communities, but with the change in situations; such as high rate of population increase, rise in current unemployment levels and hike in prices of other sources of energy; the business of fuelwood production has become increasingly prevalent in urban areas as well. It is caused by the significant rise in demand and uncontrolled consumption rates, which have led to major environmental challenges, including deforestation, land degradation, and habitat loss (Salami *et al*., 2020; Ali *et al.,* 2023). Therefore, there is an urgent need to implement sustainable management practices and controls on fuelwood production, especially in regions like savannahs, that are already experiencing severe declines in forest cover due to the conversion of limited forest land for urbanization and intensified agricultural activities (Edicha and Abdullahi, 2016; Adenle *et al.,* 2020; Assede *et al.,* 2023). Sustainable fuelwood management can play a crucial role in the socioeconomic development of the country, including poverty alleviation, and the reduction of deforestation and forest degradation. To effectively address these issues, the economic, environmental, and social status of those participating in fuelwood production as a commercial activity, as well as the technical aspects involved, are among the variables that must be thoroughly examined. This understanding will enable policymakers and practitioners to develop targeted interventions that protect and conserve forest resources, ensuring they meet the needs of both current and future generations. Currently, a proven interconnection exists between fuelwood consumption and environmental degradation; however, there appear to be inadequate data on the contributory roles of the components involved in fuelwood production as a commercial activity. Therefore, there is a need for a comprehensive understanding of the socio-economic attributes of fuelwood handlers, tree species harvested and distributed and the business structure, to promote sustainable development of forest resources. Thus, the primary objective of this study was to evaluate fuelwood handling practices in the Limawa area of Kumbotso Local Government, a fuelwood landing depot in Kano State, Nigeria. The study specifically examined the demographic characteristics of fuelwood harvesters and wholesalers in the Limawa area, including the common tree species harvested and utilised as fuelwood, their respective handling and business practices, as well as the constraints associated with fuelwood handling in the study area.

Materials and Methods

The Study Area

The study was conducted in the Limawa Area, Kumbotso Local Government Area, Kano State, Nigeria. Gezawa LGA borders Kumbotso to the north, Tarauni LGA to the south, and Dawakin Tofa LGA to the west. Limawa Area, a subunit within Kumbotso LGA, is characterised by its semi-urban environment, with a mix of residential, commercial, and agricultural land uses (Yusuf *et al.,* 2023). A tropical wet and dry climate characterizes the area. The wet season occurs between May and September, while the dry season occurs between October and April, with an annual rainfall ranging between 787 and 960 mm. The primary occupations of the people include crop farming, livestock rearing, and trading activities (Kano State Agricultural and Rural Development Authority, KNARDA, 2007). According to the 2006 census, the population of the state was estimated at 9.3 million people (National Population Commission, 2016).

Method of Sampling

A two-stage sampling technique was used to select fuelwood handlers in the study area. Limawa was purposively selected, being one of Kano's central fuelwood landing and distribution depots in the area. Second-stage sampling involves a proportionate random

selection of 42 fuelwood handlers (harvesters and marketers) from a sampling frame (population) of 60 in the study area, at a 70% intensity. The fuelwood handlers are divided into two categories: 28 fuelwood harvesters (chain saw operators) and 14 wholesalers in the study area (Table 1).

Table 1: Sampling of fuelwood handlers in the study area.

Fuelwood handlers (respondents), in the study area	Total population (sampling frame) N = 60	: 70% of handlers n = 42
Marketers/Wholesalers	20	14
Harvesters/Operators	40	28
Total	**60**	**42**

Field data, 2024

Method of Data Collection

Data for this study were collected using well-structured questionnaires, distributed to 42 fuelwood handlers (harvesters and wholesalers) in the the Limawa area. The questionnaire was sectioned into three – Section A was designed to collect data on fuelwood handler's demographic variables, Section B to collect data on sources of fuelwood species, species of fuelwood trees harvested/traded in the area, fuelwood handling and utilization in the study area and, Section C was designed to collect data on the constraints of fuelwood handling. The data were collected using well-trained enumerators in the local language.

Method of Data Analysis

Data were analysed using descriptive statistical tools, including frequency counts, percentages, mean, and modal counts. The analysis was summarised in the form of tables and charts.

Result and Discussion

Socio-economic characteristics of wholesalers in the study area

Table 2 presents the socio-economic characteristics of wholesalers in the study area. The age of wholesalers ranges between 43 and 60 years, with a mean age of 51 years. Most wholesalers (71.4%) fall within the age range of 43-51 years, while others (28.6%) were between 52 and 60 years old, indicating the wholesalers were middle-aged and older people.. Majority of the wholesalers (71.4%) have 16-30 years of experience, while a smaller proportion (28.6%) has 1-15 years of experience, indicating the wholesalers are generally experienced. The family size of wholesalers ranges from 4 to 22 members, with an average of 14 members. The majority (64.3%) have 14-23 family members, while 34.7% have 4-13 family members, indicating wholesalers have larger families, which may have implications for their financial responsibilities and decision-making.

Table 2: Socio-economic characteristics of wholesalers

Variables	**Frequency**	**Percentages**	**Mean**
Age of retailers (years)			**51.0**
43 - 51	10	71.4	
52 – 60	4	28.6	
Experience (years)			**19**
1 – 15	4	28.6	
16 – 30	10	71.4	
Size of family			**14.0**
4 – 13	5	34.7	
14 – 23	9	64.3	
Sex			
Male	14	100	

513. Female	0	0
514. **Marital status**		
515. Married	13	92.9
516. Single	1	7.2
517. **Educational status**		
518. Secondary	7	50
519. Tertiary	6	42.9
520. Islamic education	1	7.1

Field survey, 2024

All marketers (wholesalers) were males. Most of the wholesalers (92.9%) were married, while a small proportion (7.1%) was single. This suggests that marriage promotes greater dedication to business, resulting from an increase in responsibility, and also provides a more labour force for increased profitability. Wholesalers have varying educational backgrounds, with 50% having secondary education, 42.9% tertiary education, and 7.1% Islamiyyah (Islamic education). Wholesalers generally have post-primary education, which may contribute to their business acumen and decision-making skills. These findings aligned with those of Ilu *et al.* (2021) and Ariyo (2019), who found that most fuelwood traders in some parts of Kano and Kaduna States were males. It may be connected to the cultural settings of the study area.

Assessment of Tree Species Sold in the Limawa Area

Table 3 presents an assessment of tree species sold by wholesalers in the study area. It also identified some endangered and threatened species recorded in the study. Wholesalers offer a variety of tree species to their customers. The commonly sold combinations include *Anogeissus leiocarpus*, *Pterocarpus erinaceus*, *Parkia biglobosa*, *Tamarindus indica*, and *Prosopis africana* (42.8%); followed by *Anogeissus*, *Terminalia species*, Eucalyptus species, *Parkia*, *Tamarindus*, and *Diospyros* (28.6%). Other observed combinations are Anogeissus, Diospyros, Terminalia, Parkia, Eucalyptus, *Prosopis*, and *Vitellaria* (14.3%); Anogeissus, Pterocarpus, Parkia, and Ziziphus (7.1%); and Anogeissus, Pterocarpus, Balanites, *Azadirachta*, and Eucalyptus (7.1%). The finding aligns with Salisu et al. (2019) and Ali et al. (2023), who reported some of the above-listed species as common wood species available in the study area.

The most common reasons for selecting the species, based on multiple responses, include availability, profitability, and durability (42.5%), followed by availability, accessibility, and durability (28.5%). Other reasons mentioned are consumption, availability, and durability (28.5%). The majority of tree species were sourced from multiple states (71.4%), due to insufficient supply in the nearby environment, indicating a wide geographic range for obtaining the products. Some wholesalers also source from specific states, such as Kaduna and Kano (14.3%), and Kano and Bauchi (7.1%).

Wholesalers report several tree species as threatened/endangered in the area, including Doka *(Isoberlinia doka)*, Bayama (*Swartzia madagascariensis*), and Markaho (*Balanites aegyptiaca*) (28.5%), as well as Turare (E*ucalyptus camaldulensis*) and Kawo (*Afzelia africana*) (71.4%). The threat to these species may have implications for biodiversity and ecosystem health. The primary users of the tree species include household cooks and bread bakers (42.9%), as well as households, rice millers, and bread bakers (57.1%). It suggests the product is versatile in utilisation.

Table 3:Assessment of Tree Species Sold by Wholesalers in Limawa Area

521. **Variables**	522. **Frequency**	523. **Percentage**
524. **Tree species sold**	525.	526.

Anogeissus,Terminalia, Parkia, Eucalyptus, Prosopis,Diospyros	2	14.3
Anogeissus, Pterocarpus, Parkia, Tamarindus, Prosopis	6	42.8
Anogeissus, Terminalia, Eucalyptus, Parkia,Tamarindus, Diospyros	4	28.6
Anogeissus, Pterocarpus, Parkia, Ziziphus	1	7.1
Anogeissus, Pterocarpus, Balanites, Azadirachta, Eucalyptus,	1	7.1
Reasons for species preference		
Availability, accessibility, durability	4	28.5
Availability, profitability, durability	6	42.5
Consp, availability, durability	4	28.5
Source of the species		
Kano	1	7.1
Kaduna and Kano	2	14.3
Kano and Bauchi	1	7.1
Multiple states	10	71.4
Endangered/ Threatened Species		
Isoberlinia,Combretum,Balanites	4	28.5
Eucalyptus and Afzelia	10	71.4
Users/buyers		
Household cooking and bread baking	6	42.9
Household, rice millers, and bread bakers	8	57.1

Source: Field survey, 2024

Structure of Fuelwood Business

Table 4 presents the marketing mode and structure of wholesalers in the study area. All wholesalers are sole proprietors. The majority of wholesalers (78.6%) are full-time marketers, while a smaller proportion (21.4%) operates on a a part-time basis. All wholesalers belong to business cooperatives and are taxpayers. Tax compliance is crucial for maintaining legal and financial integrity, as well as supporting public services and infrastructure. The majority of wholesalers (92.8%) started their businesses using personal savings, highlighting self-reliance and entrepreneurial initiative. One wholesaler (7.1%) mentions starting the business with the support of a cooperative, indicating the role of collective efforts in facilitating business establishment. Cooperative membership may offer benefits such as collective purchasing power, shared resources, and advocacy for the interests of wholesalers (Schwettmann, 2022). This finding is similar to that of Ali et al. (2023) and Senchi and Kolo (2024), who reported a similar business structure of the fuelwood business in Yobe and Niger states, respectively.

Table 4: Structure of Fuelwood Business in Limawa

Variables	**Frequency n = 14**	**Percentage**
Business ownership		
Sole proprietorship	14	100
Mode of engagement		
Full time	11	78.6
Part-time	3	21.4
Membership in a cooperative		
Yes	14	100
Payment of Tax		
Yes	14	100
Business start-up		
Personal savings	13	92.8
Cooperatives	1	7.1

Field survey, 2024

Constraints faced by wholesalers in the study area.

Table 5 presents the constraints faced by wholesalers in the study area, allowing multiple responses. High transportation costs (100%) were identified as a significant constraint, impacting operational costs and profitability. Many wholesalers (92.8%) also report a bad road network, which can lead to delays, damage to goods during transit, and increased transportation costs. 82.5% of wholesalers cite insecurity as a constraint. Some wholesalers (78.6%) mention long distance to market as a constraint, which may lead to fatigue and consume valuable time, impacting wholesalers' efficiency and competitiveness. According to Onwo and Sylvester (2021), poor road networks and security concerns are among the major challenges facing small and medium-scale businesses

.

Table 5: Constraints faced by Wholesalers in the study area

Constraints	**Frequency**	**Percentage**
High transportation cost	14	100
Bad road network	13	92.8
Insecurity	12	82.5
Long distance	11	78.6

Source: Field survey, 2024 ***multiple response was allowed***

Socio-economic characteristics of fuelwood harvesters

Table 6 shows the socio-economic characteristics of fuelwood harvesters in the study area. All harvesters are married. Marriage leads to family responsibilities, which makes them work harder, with more working force and more profit, suggesting family responsibilities may play a significant role in their lives and businesses. Harvesters' educational backgrounds vary, with primary education (32.1%), Islamic education (32.1%), secondary (32.1%), and tertiary education (10.7%). The age of harvesters ranges from 32 to 47 years, with a mean age of 39 years. The majority fall within the age range of 38-43 years (53.6%), followed by 32-37 years (32.1%) and 44-49 years (14.3%). It suggests that the fuelwood harvesters are relatively young to middle-aged individuals.

Table 6: Socio-economic characteristics of fuelwood harvesters in the study area

Variables	**Frequency**	**Percentage**	**Mean**	
Sex				
Male	28	100		
Marital status				
Married	28	100		
Level of education				
Primary	7	25		
Secondary	9	32.1		
Tertiary	3	10.7		
Islamiyah	9	32.1		
Age (years)				39.0
32-37	9	32.1		
38-43	15	53.6		
44-49	4	14.3		
Years of experience (years)				15.0
1-8	4	14.3		
9-16	11	39.3		
17-24	13	46.4		
Number of workers				
1-5	15	53.6		
6-10	13	46.2		

Source: Field survey, 2024

Fuelwood harvesters' experience ranges from 1 to 23 years, with an average of 15 years. The majority of harvesters (46.4%) have 17-24 years of experience, some (39.3%) have 9-16 years of experience, and 14.3% have 1-8 years of experience. The majority of harvesters (53.6%) have between 1 and 5 working crew members, while 46.2% have between 6 and 10 workers. This suggests a relatively small-scale operation. The dominance of males in fuelwood harvesting may be attributed to the nature of the work, which could be a bit cruel to an average woman. The educational background of the respondents reveals that most of the harvesters did not have beyond secondary education, which is a typical characteristic of individuals engaged in informal economic activities. Such activities often rely on practical experience passed down through generations rather than formal academic qualifications (Nguyen, 2015; Bonnet and Chen, 2019). This may explain the extended years of experience among respondents, as well as the prevalence of individuals aged 32 to 49 years.

Tree Species Selection and Harvesting in the Study Area

Table 7 presents the reasons for harvesting specific tree species, sources of the harvested species, and skill acquisition in the study area. Fuelwood harvesters engage in harvesting a variety of tree species, with a focus on durability and energy value. They source their materials from various locations and acquire their skills through a combination of formal education, apprenticeship, inheritance, and specific training. The majority of tree species harvested are from farmlands (25%) and through natural forests (42.8%), indicating a mix of cultivated and naturally occurring trees. The table lists several combinations of tree species harvested. The most common combinations include *Anogeissus leiocarpus* (Marke), *Tamarindus indica* (Tsamiya), *Parkia biglobisa* (Dorowa),

and *Pterocarpus erinaceus (Madobiya*) (32.1%), followed by Tamrindus, Terminalia, and Prosopis (25%). It suggests a diverse range of tree species being harvested. Durability (35.7%) and energy value (64.3%) are significant reasons for harvesting specific tree species. This indicates a focus on selecting species that are resilient and of high energy value, which may be important factors for meeting market demand and ensuring product satisfaction. The majority of tree species are sourced from multiple states (35.7%), with other familiar sources including Kaduna and Kano (21.4%), Kano and Sokoto (21.4%), and Kano and Gombe (14.3%). This study indicates there is a broad geographic range for obtaining tree species indicating a diverse supply chain network among harvesters. However, this also highlights the depth of the unsustainable harvesting culture surrounding fuelwood extraction in the study area. Trees on farms have their own advantages for the mixed crops planted around them, and they perform environmental functions such as windbreak and erosion control (Fleming *et al.,* 2019; Oyelami and Osikabor, 2022).

Additionally, the harvesters to obtain the species from places as far as Gombe and Sokoto states which are two opposite extremes from the study area. This could mean the depletion of the preferred species in the study area, showcasing the level of pressure this type of activity could exert on the dwindling forest cover in the vegetation zone. This issue is not limited to Nigeria alone; studies have shown that countries in sub-Saharan Africa have lost more than half of their forest cover as a result of uncontrolled tree cutting for fuel use (Sulaiman *et al.,* 2017; Singh *et al.,* 2021). Thus, this will necessitate a proactive action the manage the activities of the fuelwood harvester to reduce further damage to the environment.

Table 7: Tree species selection and harvesting in the study area

Variables	**Frequency**	**Percentage**
Source of harvested trees		
Natural Forests	12	42.8
Plantations	1	3.5
Farmland	7	25
Open land	8	28.6
Tree species harvested		
Terminalia, Pterocarpus, Parkia	4	14.2
Diospyros, Terminalia, Acacia, Azadirachta	2	7.1
Prosopis, Diospyros, Terminalia,	2	7.1
Anogeissus, Prosopis, Parkia	4	14.1
Anogeissus,Tamrindus,Parkia, Pterocarpus	9	32.1
Tamarindus, Terminalia, Prosopis	7	25
Reasons for species selection		
Durable	10	35.7
Energy value	18	64.3
Source of the species		
Multiple states	10	35.7
Kaduna and Kano	6	21.4
Kano and Sokoto	6	21.4
Kano and Bauchi	2	7.1
Kano and Gombe	4	14.3

Source of skill acquisition		
Technical education	8	28.5
Inheritance	15	53.6
Apprenticeship	1	3.5
Artisanship	4	14.1

Source: field survey, 2024

Conclusion and recommendations

There are five commonly traded fuelwood species recorded in the study area. Traders selected these species based on their availability, profitability and durability. The species were harvested from natural forests located in a wide geographical range across the northern part of Nigeria, with five species recorded as being under threat. All fuelwood marketers were observed to be full-time sole proprietors who commenced their businesses with their savings, and are members of business cooperatives. The most significant marketing constraint in the study area is the high cost of transportation. Most fuelwood harvesters are small to medium-scale operators. Fuelwood species were harvested based on their energy value.

Based on the findings of the study, the following recommendations are made:

1. It is essential for the government to invest in upgrading road networks and transportation infrastructure to facilitate the supply of forest goods.
2. Collaboration among stakeholders is essential to foster knowledge-sharing, cooperative marketing, and joint resource management for mutual benefits.
3. The government should provide financial assistance for infrastructure improvements and training programs to support skill development.
4. The government and relevant stakeholders should promote the adoption of sustainable forestry practices by preserving natural resources, adopting sustainable harvesting methods, and participating in certification programs.

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METABOLIC ENGINEERING FOR BIOFUEL PRODUCTION

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ABSTRACT

Metabolic engineering is a multidisciplinary field that combines principles of chemistry, biology, geneticss, and engineering to manipulate and optimise cellular metabolic pathways for the production of valuable compounds, such as biofuels, pharmaceuticals, and industrial chemicals. It offers an alternative approach in which synthetic pathways are engineered into user-friendly hosts for the production of these fuel molecules. This field has gained significant attention and importance in recent years due to its potential to address global challenges related to energy production. The goal of metabolic engineering is to design and modify microbes to enhance the production of desired products in a more efficient and cost-effective manner. It plays a crucial role in the production of biofuels, which are inflammable fuels made from biomass, such as starch and agricultural waste. It is classified based on its production, such as bioethanol, biodiesel, and biogas. Biofuel is of great importance because it can reduce greenhouse gas emissions and also create new opportunities for economic development. The challenges for scaling up biofuel production include infrastructure requirements, technology limitations, etc. This paper concludes that by redesigning and fine-tuning metabolic pathways in microorganisms, building infrastructure, and improving technology, researchers can enhance their ability to produce biofuel in a cost–effective and sustainable manner.

Keywords: Metabolic Engineering, biofuel, sustainable fuel production, microorganism and renewable resources.

INTRODUCTION

Metabolic engineering is a field that has grown in importance in recent years, as the world continues to search for sustainable and renewable sources of energy (Singh and Bhardway, 2020). In particular, biofuels have emerged as a promising alternative to traditional fossil fuels, offering a more environmentally friendly option for powering our societies. Metabolic engineering plays a crucial role in the production of biofuels by manipulating the metabolic pathways of organisms to increase their efficiency in producing biofuels (Linc and Li, 2018). Biofuels are flammable fuels made from biomass, such as starch and agricultural waste. It is a fuel made from recently living plant material, not from old, hydrocarbon-rich plant material. Biofuel is commonly used to refer to liquid fuels, such as ethanol (alcohol produced from the fermentation of sugar and starch crops like corn) and biodiesel (produced from vegetable oil), which are used as alternatives to transportation fuels, such as petroleum and jet fuel (Brandt *et al.,* 2018). The production of biofuel has several environmental benefits compared to the production of fossil fuels. Biofuel producess lower levels of greenhouse gas emissions, such as carbon dioxide, methane, and nitrogen oxides, which contribute to climate change (Sarma et al., 2012). They also reduce our dependence on fossil fuels and help to mitigate the environmental impact of driving, mining and transporting these fuels. The main challenge of scaling up biofuel production is feedstock availability, and expanding the range of

feedstock sources used for biofuel production can help ensure a more sustainable and diverse supply of biomass (Gomeya *et al.,* 2012).

BRIEF HISTORY OF METABOLIC ENGINEERING

Metabolic engineering is a rapidly growing field that intersectss biology, chemistry, and engineering to design and optimise pathways within cells for the biosynthesis of valuable products. One of the most prominent applications of metabolic engineering is the production of biofuels, which are sustainable alternatives to fossil fuels that can help reduce greenhouse gas emissions and dependence on finite resources (Lapointe *et al*; 2020).

The history of metabolic engineering for biofuel production can be traced back to the early days of the field, when researchers first began to explore the potential for using microorganisms to produce biofuels (Lapointe et al., 2020). In the 1970s and 1980s, scientists began to genetically engineer bacteria and yeast to produce ethanol, an alternative fuel derived from renewable sources such as corn or sugarcane. This early experiment laid the foundation for the development of metabolic engineering techniques that are now widely used in biofuel production.

In the 1990s, Gregory Stephanopoulos, a chemical engineer, played a significant role in advancing metabolic engineering by developing strategies to manipulate cellular pathways for the production of biofuels and other valuable chemicals (Nair *et al.,* 2021). His work paved the way for the use of metabolic engineering in industrial applications.

In the early 2000s,, Jay Keasling, a chemical engineer and synthetic biologist, made groundbreaking discoveries in metabolic engineering by engineering microbes to produce artemisinin, a key ingredient in the treatment of malaria. This achievement demonstrated the potential of metabolic engineering to address global health challenges. In the early 2000s, metabolic engineering researchers began to focus on developing biofuels that are more compatible with existing infrastructure, such as biodiesel, a renewable fuel made from vegetable oils or animal fats. By engineering microorganism to produce biodiesel precursors, such as fatty acids and triglycerides, researchers were able to create new pathways for producing sustainable biofuels that can be easily integrated into existing transportation systems.

Overall, the history of metabolic engineering for biofuel production is a tale of innovation and discovery as scientists continue to push the boundaries of what is possible in creating sustainable and renewable sources of energy. As the world transitions towards a more sustainable future, metabolic engineering will play a crucial role in creating a new generation of biofuels that can help reduce our reliance on fossil fuels and mitigate the impacts of climate change.

OVERVIEW of BIOFUELS

Biofuels are a renewable and sustainable source of energy produced from biological materials such as plant biomass, animal waste, or algae (Rajendran and Rajagopal 2018). These materials are converted into liquid or gaseous fuels that can be used as an alternative to fossil fuels in transportation, heating and electricity generation. They are a type of energy fuel derived from organic sources created by plants and living things, which can be grown and harvested repeatedly. Biofuels used to replace non-renewable energy fuels are sourced clearly from agricultural and vital harvesting, woodlands and residue streams (Nasir *et al*., 2021). Biofuels are typically in the form of biodiesel, ethanol and biogas. Biodiesel is produced from vegetable oils, animal fats, or recycled cooking oil through a process called transesterification (Brandt et al., 2018). Ethanol is primarily produced from crops such as corn, sugarcane, or wheat through a fermentation process. Biogas is produced from organic waste materials, such as food scraps, manure, or sewage, through the process of anaerobic digestion. Petroleum oil is one of the world's most important energy sources. The transportation sector utilises more than 70% of all petroleum products. As the petroleum usage is rising significantly, it is estimated that by 2070 – 2080, the world will fall short of petroleum oil its overuse has given rise to concerns about well- being and global warming due to greenhouse gas emissions (GHG),

consisting of co_2 and other toxic gases such as methane carbon monoxide and chlorofluorocarbons (Laptitore *et al*; 2020).
Biofuels are developed as a substitute for petroleum because of their non-toxic, sulfur-free, biodegradable nature, originating from renewable sources. The production of biofuel has several environmental benefits compared to the production of fossil fuels. Biofuels produce lower levels of greenhouse gas emissions, such as carbon dioxide, methane and nitrogen oxides, which contribute to climate change (Sarma *et al*., 2012). They also reduce our dependence on fossil fuels and help to mitigate the environmental impact of driving, mining, and transporting these fuels. Depending on the feedstock, biofuels are categorised into four types: 1st, 2nd, 3rd, and 4th generation biofuels, respectively.

Importance of Biofuel as a Renewable Energy Source

i. **Renewable**: Biofuels are derived from organic materials such as crops, waste or algae, making them a renewable and sustainable energy source. Unlike finite fossil fuels, biofuels can be produced continuously through agricultural and industrial processes.

ii. **Reduced greenhouse gas emissions**: Fossil fuels generate large amounts of greenhouse gases when burned, high carbon (iv) oxide is generated into the atmosphere. Biofuels produce lower levels of greenhouse gas emissions compared to traditional fossil fuels. The carbon dioxide released during the combustion of biofuels is offset by the carbon dioxide absorbed during the growth of the biomass, making them a more environmentally friendly alternative.

iii. **Energy security**: Biofuels can help reduce dependence on foreign oil sources and enhance energy security by diversifying the energy mix. By reducing their reliance on biofuels domestically, countries can stabilise their energy supplies and reduce their reliance on volatile global oil markets.

iv. **Environmental benefits**: Biofuel production can help improve air quality, reduce water pollution and increase biodiversity by promoting sustainable land use practices. In all, biofuel production plays a crucial role in transitioning towards a more sustainable and environmentally friendly energy system (Rajendian *et al*., 2018)

v. **Economic development**: Biofuel production can create new opportunities for economic development, particularly in rural areas where biomass feedstock is grown and processed. The biofuels industry can generate jobs, stimulate local economies, and contribute to overall economic growth.

Classification of Biofuel

Three classifications provide a framework for understanding the diversity of biofuels and the advancements made in developing sustainable, renewable alternatives to traditional fossil fuels. Ongoing research and innovation in biofuel technologies continue to expand the range of biofuel options and improve their efficiency, environmental performance and economic viability. (Signh and Bhardwa 2020).

Classification Based On Generation

(a) **First-generation biofuels**: Derived from food crops and conventional production processes.

(b) **Second-generation biofuels:** Produced from non-food biomass sources using advanced conversion technologies like cellulosic ethanol and biomass–based diesel.

(c) **Third generation biofuels**: Generated from microalgae or other unconventional feedstocks with high lipid content and rapid growth rates (Ho *et al.,* 2019).

(d) **Fourth-generation biofuels:** Focus on integrating biofuel production with carbon capture and storage technologies to achieve net-negative emissions.

Classification Based On Production Process

(a) **Bioethanol**: It is the most widely used biofuel, which is produced through the fermentation of sugars by yeast or bacteria. Metabolic engineering strategies for bioethanol production include optimising sugar utilisation, increasing ethanol tolerance, and enhancing ethanol yield. For example,, researchers have engineered a yeast strain with improved xylose fermentation capabilities, allowing for the use of sugars from biomass as a feedstock for bioethanol production (Taharazadeh and Kazimi, 2011). One of the main advantages of bioethanol is its compatibility with existing

gasoline infrastructure, making it easier to integrate into the transportation sector. There are also challenges associated with bioethanol production, such as competition with food crops for land and water resources. Limited feedstock availability and high energy input required for the conversion process

(b) **Biodiesel**: It is another essential biofuel produced through the transesterification of vegetable oils, animal fats, or recycled cooking oil. Metabolic engineering approaches for biodiesel production involve optimizing. The lipid metabolism of oleaginous microorganismss, such as algae and yeast, is used to increase lipid accumulation and productivity (Balat, 2011).

(c). **Biogas**: It is a renewable fuel produced from the anaerobic digestion of organic matter, such as agricultural waste, sewage and food scraps. Biogas production involves the collection and pre-processing of feedstock, anaerobic digestion, biogas purification, and utilisation (Lee *et al*., 2008). Biogas offers several environmentalal benefits, including reduced methane emissions from organic waste decomposition, diversion of waste from landfills, and potential natural recycling. However, challenges associated with biogas production include feedstock quality and availability, as well as process efficiency and technology costs.

Biofuel Producing Micro Organism and their Metabolic Pathway

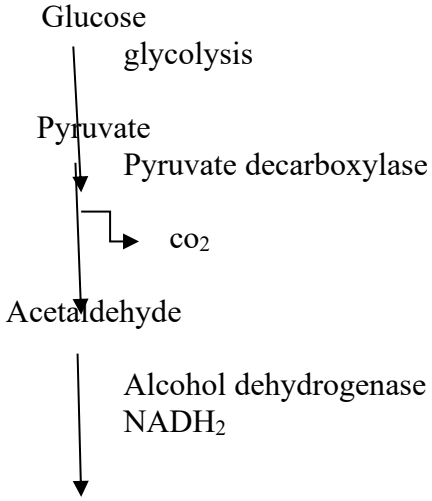
A metabolic pathway is a a series of chemical reactions that occur in living organisms to produce energy and essential molecules for cellular processes. In biofuel production, metabolic pathways are used to convert Renewable biomass into biofuels such as ethanol.

The metabolic pathway plays a crucial role in the production of biofuels by providing the necessary biochemical foundations for converting renewable feedstocks (such as sugar) into valuable fuel molecules. These pathways are a complex network of interconnected biochemical reactions that take place within cells, involving enzymes, substrates, and cofactors to catalyse specific chemical transformations (Fitzgerald, 2016). One of the most common metabolic pathways for biofuel production is glycolysis, which involves the breakdown of glucose into Pyruvate. Pyruvate can then be further metabolised through fermentation to produce ethanol or through the citric acid cycle to produce acetyl-CoA, which is used to produce biodiesel.

Types of microorganisms that are used in the production of biofuels include the following;

1. **Yeast**: Yeast is commonly used in the fermentation process to produce bioethanol from sugars derived from crops such as sugarcane and corn. Yeast enzymes break down sugars into ethanol and carbon dioxide.
2. **Algae**: Algae are a diverse group of photosynthetic microorganisms that can be used to produce biofuel such as bioethanol, biodiesel
3. **Bacteria**: Certain types of bacteria, such as Clostridium and Escherichia, can produce biofuels through the fermentation of sugar or other feedstocks. These bacteria can produce biofuels such as ethanol, butanol, and hydrogen.

Metabolic Pathway for the Production Of Bioethanol By Yeast (*Saccharomyces Cerevisiae*)



Ethanol

It involves the following steps;

1. Sugar uptake: yeast uptakes sugars such as glucose from the environment
2. Glycolysis: glucose is metabolized through the glycolysis pathway to produce pyruvate. Glycolysis involves a series of enzymatic reactions that break down glucose into pyruvate, generating ATP and NADH as energy carriers.

3. Decarboxylation of pyruvate: Pyruvate produced from glycolysis, is decarboxylase to acetaldehyde by the enzyme pyruvate decarboxylase, releasing carbon dioxide
4. Reduction of acetaldehyde to ethanol; acetaldehyde is reduced to ethanol by the enzyme alcohol dehydrogenase using NADH as a cofactor.

5. Ethanol production: The final product of the pathway is ethanol, which is excreted by the yeast cells into the fermentation medium. Ethanol can be collected and purified for use as bioethanol fuel.

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Challenges Faced in Scaling Up Biofuel Production

Scaling up biofuel production presents several challenges that need to be addressed to achieve commercial viability and widespread adoption. Some of the key challenges include the following;
(i). **Feedstock availability and sustainability:** One of the main challenges for scaling up biofuel production is ensuring a sustainable and reliable supply of feedstock. The production of biofuel requires a large quantity of biomass, such as crop residue, energy crops, or waste materials. Ensuring a consistent and affordable supply of feedstock can be a major hurdle, especially in regions where competition with food production or land-use constraints exist (Gomeya *et al*., 2012).
(ii). **Technological Limitations**: Scaling up biofuel production often requires the development of advanced technologies and processes to increase efficiency, reduce costs, and improve the overall economics of production. Developing and implementing these technologies can be time-consuming and costly, and may also require significant investments in research and development.

(iii) **Infrastructure requirements:** Scaling biofuel production often requires the development of adequate infrastructure, such as biofuel processing facilities and storage facilities. Building this infrastructure can be a significant challenge, especially in regions where existing infrastructure is lacking or inadequate
(iv) **Policy and regulatory challenge**: Government policies and regulations can have a significant impact on scaling up biofuel production. Unfavourable policies, such as subsidies for fossil fuels or restrictions on biofuel use, can hinder the growth of the biofuel industry. Developing a supportive policy and regulatory environment is essential for fostering growth and investment in the biofuel sector.
(v) **Economic viability**: One of the biggest challenges in scaling up biofuel production is achieving economic viability and competitiveness with conventional fossil fuels. The high costs of production, transportation and distribution can make biofuel less competitive in the market, especially when oil prices are low. Developing strategies to reduce costs, increase efficiency and improve the overall economics of biofuel production is crucial for scaling up the industry.

Strategies for Scaling up Biofuel Production

(a). **Diversifying feedstock source:** Expanding the range of feedstock sources used for biofuel production can help ensure a more sustainable and diverse supply of biomass. It can include using non-food crops, algae, waste materials, and other biomass sources that do not compete with food production.

(b) Improving technology and process efficiency: Investing in research and development to enhance the efficiency of biofuel production processes can help reduce costs, increase yields, and improve overall sustainability. This can involve developing new technologies, optimizing existing processes, and increasing the scale of production facilities
(c) Developing supportive policies and incentives: Governments can play a key role in supporting the scaling up of biofuel production by implementing policies and incentives that promote the use of biofuels, such as mandates, tax credits, and subsidies. Creating a supportive policy environment can help attract investments, stimulate growth and encourage innovation in the biofuel industry
(d) Building infrastructure: Developing the necessary infrastructure for biofuel production, distribution, and storage is essential for scaling up the industry.This can involve building new processing facilities, expanding distribution networks and investing in transportation and storage infrastructure to support the growth of biofuel production.
(e) Collaborating with industry stakeholders: Collaboration between the government, industry, research institutions, and other stakeholders is essential for scaling up biofuel production.Working together to share knowledge, resources, and expertise can help overcome challenges, drive innovation, and accelerate the growth of the biofuel industry.
By addressing these challenges and implementing these strategies, the biofuel industry can overcome barriers to scaling up production and realize its full potential as a sustainable and renewable energy source.

CONCLUSION

Metabolic engineering holds immense potential for advancing biofuel production and accelerating the transition into more sustainable energy. The potential impact of metabolic engineering in biofuels extends beyond just replacing traditional fossil fuels. Biofuels produced through this technology can also help reduce greenhouse gas emissions, mitigate climate change and enhance energy security. It holds great promise for biofuel production, as it allows for the optimisation of microbial cell factors to efficiently convert renewable feedstocks into biofuel. By manipulating the metabolic pathways of microorganismss, researchers can enhance their ability to produce biofuels at a larger scale and with higher efficiency. This technology has shown successful results in the production of biofuels such as ethanol, butanol, and biodiesel.

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SUBTHEME 6: ECONOMIC VALUATION AND POLICY FRAMEWORKS FOR SUSTAINABLE FOREST CONSERVATION IN INSECURE REGIONS

ETHNOBOTANICAL AND SOCIO-ECONOMIC ANALYSIS OF MEDICINAL PLANTS IN OSHO FOREST RESERVE, NIGERIA

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ABSTRACT

This study investigates the ethnobotanical uses and socio-economic impact of medicinal plants in the Osho Forest Reserve. Data were collected using a well-structured questionnaire administered to local respondents who are involved in medicinal plant harvesting and marketing. The data obtained were subjected to analysis using descriptive and budgetary analysis. The findings reveal that leaves are the most commonly used part of the plant, reflecting sustainable harvesting practices. Medicinal plants play a crucial role in traditional healthcare, poverty alleviation, and community well-being. Economic analysis shows that medicinal plant marketing is profitable, with a benefit-cost ratio of 1.80 and a rate of return of 72.65%, indicating a viable source of income for local people. Despite these benefits, challenges such as resource depletion and market access hinder sustainable utilization. The study highlights the importance of integrating traditional knowledge with sustainable management to conserve medicinal plant resources while improving local livelihoods.

Keywords: Ethnobotany, medicinal plants, Phytochemicals, socio-economic impact, Osho Forest Reserve

INTRODUCTION

Tropical rainforests provide a wide array of products essential to the livelihoods of many communities, especially in developing countries where about 80% of the population depends on non-wood forest products for nutrition and health (Faleyimu, 2000). In Nigeria, forests provide diverse wood and non-wood resources, as well as critical social and environmental benefits (Oyebo, 2003). Although medicinal plants contribute a small portion to national agricultural output, their high market value makes them essential cash crops, particularly for remote subsistence farming communities with limited access to regional markets (Chauhan, 2010).

Ethnobotanical studies are crucial for documenting and understanding the relationship between biodiversity and human societies, particularly in how indigenous plants are utilized for food, medicine, clothing, and other purposes (Martin, 1995; Aiyeloja and Bello, 2006). Such documentation is critical for the conservation and sustainable use of biological resources (Muthu *et al.,* 2006). The involvement of local communities in biodiversity conservation through ethnobotanical knowledge is crucial, as many of the world's healthiest ecosystems are managed by indigenous people with invaluable traditional knowledge (Hamilton, 2003).

Since the dawn of civilization, plants have played a crucial role in traditional medicine, with many active compounds derived from

plants forming the basis of modern pharmaceuticals (Gupta *et al.,* 2010). Medicinal plants remain a rich source of therapeutic agents used in both traditional and modern medicine systems (Edeoga *et al.,* 2005; Ncube *et al.,* 2008). Their medicinal properties primarily result from phytochemicals—non-nutritive compounds with protective or disease-preventive effects (Shittu *et al.,* 2011). Despite their importance, the use and conservation of medicinal plants face challenges such as deforestation, urbanization, and poor documentation, which limit awareness and proper utilization, particularly among rural users (Dery *et al.,* 1991).

Economically, investment in medicinal plant-based businesses is declining due to perceptions of low profitability. However, proper documentation can enhance awareness, promote sustainable use, and empower communities through income generation. Given the significant role medicinal plants play in healthcare and rural livelihoods, systematic documentation and increased public awareness are urgently needed to harness their full potential for national development.

METHODOLOGY

This study was conducted in the Osho Forest Reserve, located in Ido Local Government Area of Oyo State, Nigeria, within the derived savanna ecological zone characterized by a tropical climate with two distinct wet seasons and one dry season, and an average annual rainfall of about 1257 mm (Ismail *et al.,* 2017). Six major villages surrounding the reserve—Onikanga, Mabole, Onifufu, Agba, Abule, and Agbatu—were selected based on their population sizes. A total of 114 respondents were sampled using a stratified sampling technique, based on population percentages as recommended by Diaw *et al.* (2002).

Primary data for this study were collected using structured questionnaires focused on respondents' socio-economic characteristics, medicinal plant identification, utilization, and the socio-economic impact of these plants on rural livelihoods. Six villages around Osho Forest Reserve were purposively selected, and respondents were sampled using a population-based intensity method, resulting in 114 questionnaires administered. To assess the economic impact of medicinal plants, budgetary analysis was conducted by calculating gross margin (GM), net margin (NM), and net income (NI) using the following equations:

$$GM = TR - TVC \quad (1)$$

$$NM = GM - TFC \quad (2)$$

$$NI = TR - TC \quad (3)$$

where TR = total revenue, TVC = total variable cost, TFC = total fixed cost, and TC = total cost (fixed + variable). Additional ratios, such as benefit rate and expense structure ratio, were calculated as:

$$\text{Benefit Rate} = \frac{\text{TR}}{\text{TFC}} \quad (4)$$

$$\text{Expense Structure Ratio } \frac{\text{FC}}{\text{VC}} \quad (5)$$

This budgetary approach enabled the quantification of the profitability and cost efficiency of medicinal plant use, providing insight into their socio-economic importance in the study area.

RESULTS AND DISCUSSION

Socio-Economic Characteristics of Respondents

Table 1 shows the results of socio-economic characteristics from a total of 117 respondents. The gender distribution reveals that females (58.97%) outnumber males (41.03%). It suggests that women are more involved in the use and sale of medicinal plants than men. In many communities worldwide, men and women have different gender-based roles, responsibilities, and knowledge systems, especially regarding access to and control over natural resources (Augustino and Gillah, 2005).

The age distribution indicates that the majority of respondents (29.06%) fall within the 41–50 years age range, followed by those aged 51–60 years (23.08%). The least represented age group

is 21–30 years, accounting for 11.97%. It suggests that older individuals are more knowledgeable and experienced in using medicinal plants. This finding aligns with Kajumbe *et al.* (2008), who reported similar trends in the Usambara Mountains. However, in the Uhegura Mountains, younger people were more actively involved in utilizing medicinal plants. Similarly, in Kenya, Quiroz (1994) found that individuals below 20 years old had limited knowledge of medicinal plants compared to those over 50 years old.

Regarding marital status, the results show that the majority of respondents are married (74.36%), followed by singles (13.68%), widows (11.11%), and divorced individuals (0.85%). It indicates a dominance of married individuals in the study area. In terms of household size, 35.04% of respondents reported having seven or more members, while 25.64% have between 3 and 4 members, and 15.38% have fewer than three members. Larger household sizes may imply the availability of more hands to assist in various medicinal plant-related activities.

Educational status results reveal that most respondents hold primary education (55.55%), followed by those with secondary education (35.90%), while a small number have tertiary education (3.42%). It suggests that individuals with primary education are more involved in the use and trade of medicinal plants than those with higher educational qualifications. Those with tertiary education are likely to spend more time in urban areas, online, or engaged in business and other modern occupations, thereby reducing their exposure to traditional knowledge. According to Kweka (2004), it is not surprising that the most educated individuals tend to have limited knowledge of medicinal plants, as they often spend less time in rural settings.

Table 1: Socio-economic characteristics of the respondents

Variables	Category	Frequency N = 117	Percentage (%)
Gender	Male	48	41.03
	Female	69	58.97
Age	21–30	14	11.97
	31–40	19	16.24
	41–50	34	29.06
	51–60	27	23.08
	61 and above	23	19.65
Marital Status	Single	16	13.68
	Married	87	74.36
	Divorced	1	0.85
	Widow	13	11.11
Household Size	<3	18	15.38
	3–4	30	25.64
	5–6	28	23.94
	7 and above	41	35.04
Educational Status	No formal education	6	5.13
	Primary education	65	55.55
	Secondary education	42	35.9
	Tertiary education	4	3.42
Occupation	Trader	27	23.08
	Student	19	16.23
	Teacher	10	8.55
	Farmer	61	52.14

Identification of Some Medicinal Plants

A total of 34 medicinal plant species, belonging to 25 plant families, were identified in the study area (Table 2). These species are traditionally

used for the treatment and management of various ailments. Among the identified species, *Mangifera indica* (Mango) had the highest frequency of occurrence (64), indicating it is the most widely available and utilized medicinal plant in the study area. It is followed by *Azadirachta indica* (Neem) with a frequency of 41. On the other hand, *Alstonia boonei*, *Kigelia africana*, *and Newbouldia laevis, among others,* had the lowest frequency of occurrence (1), indicating their limited availability or usage.

The results also show that the *Anacardiaceae family* had the highest number of plant species used in traditional medicine, emphasizing its importance in the local medicinal system. Other families with notable representation include *Asteraceae, Euphorbiaceae*, *Liliaceae, Sapotaceae*, and *Rutaceae,* which aligns with other ethnobotanical studies in Nigeria and beyond. For instance, previous research in the Niger Delta region identified *Euphorbiaceae* as one of the most commonly used medicinal families (Ajibesin et al., 2008), while studies in Ethiopia reported similar findings, including *Euphorbiaceae* and *Asteraceae* (Teklehaymanot and Giday, 2007).

The Fidelity Level (FL%), which reflects the percentage of informants citing the use of a plant species for the same significant ailment, also supports the popularity and consistency in usage. *Mangifera indica* had the highest FL of 54.7%, while species such as *Alstonia boonei*, *Kigelia africana*, and *Mucuna pruriens* recorded the lowest FL (0.9%), indicating lesser consensus or specific application among respondents.

Table 2: Identification of some medicinal plants in the study area with their botanical name, common name, and local name

S/N	Family	Botanical Name	Common Name	Local Name	Frequency of Occurrence	Fidelity Level (%)	Ranking
1	*Anacardiaceae*	*Anacardium occidentale L.*	Cashew	Kaju	8	6.8	7th
2	*Anacardiaceae*	*Mangifera indica L.*	Mango	Mangoro	64	54.7	1st
3	*Annonaceae*	*Annona muricata L.*	Soursop	Abo	7	6	8th
4	*Apocynaceae*	*Alstonia boonei De Wild.*	Alstonia	Ahun	1	0.9	14th
5	*Apocynaceae*	*Rauvolfia vomitoria Afzel*	Indian snake root	Asofeyeje	3	2.6	12th
6	*Asteraceae*	*Ageratum conyzoides L.*	Goat-weed	Imi-esu	13	11.1	4th
7	*Asteraceae*	*Vernonia amygdalina Delile*	Bitter-leaf	Ewuro	9	7.7	6th
8	*Bignoniaceae*	*Kigelia africana L.*	Sausage	Pandoro	1	0.9	14th
9	*Bignoniaceae*	*Newbouldia laevis Beaun*	Tree of Life	Akoko	1	0.9	14th
10	*Bombacaceae*	*Adansonia digitata L.*	Baobab	Ose	2	1.7	13th
11	*Caesalpiniaceae*	*Senna alata L.*	Senna	Asuwon oyinbo	6	5.1	9th
12	*Clusiaceae*	*Garcinia kola Heckel*	Bitter kola	Orogbo	7	6	8th
13	*Combretaceae*	*Terminalia catappa L.*	Almond tree	Idi	22	18.8	3rd
14	*Combretaceae*	*Terminalia ivorensis L.*	Black Afara	Afara	4	3.4	11th
15	*Cucurbitaceae*	*Citrullus lanatus Thumb*	Watermelon	Egusi	4	3.4	11th

16	*Euphorbiaceae*	*Jathropha curcas L.*	Physics nut	Lapalapa	11	9.4	5th
17	*Labiatae*	*Ocimum gratissimum L.*	Clove	Efinrin	4	3.4	11th
18	*Fabaceae*	*Mucuna pruriens (L.) DC.*	Mucuna beans	Werepe	1	0.9	14th
19	*Fabaceae*	*Tetrapleura tetraptera L.*	Gum tree	Aidan	3	2.6	12th
20	*Liliaceae*	*Allium sativum L.*	Garlic	Ayu	5	4.3	10th
21	*Liliaceae*	*Aloe vera L.*	Aloes	Apa	11	9.4	5th
22	*Lythraceae*	*Lawsonia inermis L. Webb*	Henna	Laal	9	7.7	6th
23	*Meliaceae*	*Azadirachta indica L.*	Neem	Eke oyibo	41	35	2nd
24	*Meliaceae*	*Khaya senegalensis Juss*	Dry-zone mahogany	Oganwo	2	1.7	13th
25	*Moraceae*	*Ficus exasperata A. Chev*	Sandpaper leaf	Erepin	5	4.3	10th
26	*Moringaceae*	*Moringa oleifera Lamk*	Drumstick	Ewe igbale	6	5.1	9th
27	*Palmae*	*Cocos nucifera L.*	Coconut tree	Igi-Agbon	8	6.8	7th
28	*Rutaceae*	*Citrus limon L. Burnf.*	Lemon	Orombo-wewe	4	3.4	11th
29	*Sapotaceae*	*Butyrospermum parkii G. Don*	Shea butter tree	Emi-emi	6	5.1	9th
30	*Sterculiaceae*	*Treculia africana L.*	African breadfruit	Afon	4	3.4	11th
31	*Sterculiaceae*	*Triplochiton scleroxylon L.*	Obeche	Arere	4	3.4	11th
32	*Tilliaceae*	*Corchorus olitorius L.*	Jute	Ewedu	1	0.9	14th
33	*Verbenaceae*	*Vitex doniana Sw.*	Black plum	Oori	3	2.6	12th

34	*Zingiberaceae*	*Aframomum melegueta Roscoe*	Alligator pepper	Ataare	3	2.6	12th

Utilization of Some Medicinal Plants

Table 3 presents the botanical names, families, ailments treated, plant parts used, and the methods of preparation, administration, and dosage of medicinal plants recorded in the study. The most common preparation method was decoction, followed by infusion and juice. This finding aligns with reports from Babungo, Cameroon (Simbo, 2010) and other regions worldwide, where decoction is also widely used (Sankaranarayanan *et al.,* 2010). Single-plant remedies were more prevalent than multi-plant combinations, consistent with traditional medicinal practices observed in countries like Bangladesh and Peru (Hossan et al., 2010). The ailments treated include malaria, skin diseases, wounds, burns, and digestive problems such as stomach ache, diarrhea, dysentery, and worm infestations, often diagnosed through visual examination. Skin diseases were the most frequently reported, encompassing conditions like rashes, spots, and eczema. The prevalence of digestive ailments may be linked to poor sanitation and contaminated water sources. Malaria, a significant health challenge locally, is similarly treated with various medicinal plants in other countries, such as Brazil (Botsaris, 2007). However, there is concern over the declining transmission of indigenous knowledge, which has been traditionally passed down through generations (Kideghesho, 2008), underscoring the need for its documentation and preservation.

Table 3: Utilization of some medicinal plants with the parts used, method of preparation, administration, and dosage

S/N	Scientific Name	Part Used	Ailment	Preparation / Administration / Dosage
1	*Anacardium occidentale L.*	Nut, bark, and leaves	Ringworm, cough, insect repellent	Eat roasted nuts three times daily, or use an infusion of bark and leaves as a lotion.
2	*Mangifera indica L.*	Bark and leaves	Malaria	Drink a cup of decoction thrice daily.
3	*Annona muricata L.*	Fruits, leaves, flowers	Fever, diarrhoea	Infusion with 2–3 leaves per litre of water, three cups daily.
4	*Alstonia boonei De Wild.*	Bark	Fever	Bark infusion, three cups daily.
5	*Rauvolfia vomitoria Afzel.*	Roots and rhizomes	Breathing problem	50–100 g of root powder dissolved in water, taken twice daily.
6	*Ageratum conyzoides L.*	Leaves, stems, and flowering tops	Abdominal pain, cough, cold, back pain, fever, skin diseases	Leaf decoction or juice.
7	*Vernonia amygdalina Delile*	Leaves	Stomach pain, fever, diabetes	Decoction of leaves taken before meals.
8	*Kigelia africana L.*	Fruits and roots	Eye problems	A decoction is used as an eyewash every morning.
9	*Newbouldia laevis Beauv.*	Leaves, bark, roots	Skin diseases, smallpox	Leaf decoction or root powder.

10	*Adansonia digitata L.*	Pulp of fruit, young leaves	Diarrhoea, liver damage	Fresh pulp mixed with water, taken raw.
11	*Senna alata L.*	Roots and leaves	Eczema, pile	Infusion of powdered root in water, twice daily.
12	*Garcinia kola Heckel*	Root and seeds	Throat infection, asthma, and digestion	Infusion of the root with salt or ground seed.
13	*Terminalia catappa L.*	Leaves, bark, and root	Threatening abortion, fever	Juice or smudge of young leaves with oil.
14	*Terminalia ivorensis L.*	Root and bark	Fever	Decoction of root and bark.
15	*Citrullus lanatus Thunb.*	Fruits and seeds	Snakebite, scorpion sting	Ground seed is taken three times daily or used as a poultice.
16	*Jatropha curcas L.*	Leaves	Dysentery, cough	Leaf decoction.
17	*Ocimum gratissimum L.*	Leaves	Cough, abdominal pain, cold	Leaf decoction or juice.
18	*Mucuna pruriens (L.) DC.*	Seeds	Performance enhancement	5 mg ground seed powder or cooked fresh shoots; soak seeds for 30–45 hours before cooking.
19	*Tetrapleura tetraptera L.*	Root	Asthma	Root decoction.
20	*Allium sativum L.*	Bulb	Diarrhea, hypertension, wounds	Extract capsules or decoction of cloves.
21	*Aloe vera L.*	Leaf juice	Immunity, ulcers, and asthma	Juice is taken twice daily and used as a lotion.

22	*Lawsonia inermis L. Webb*	Leaves and roots	Skin problems, anti-bacterial	A leaf poultice can be applied as a wash or a paste.
23	*Azadirachta indica L.*	Leaves	Malaria	Leaf decoction is taken thrice daily.
24	*Khaya senegalensis Juss.*	Root bark	Worms, wounds, ulcers	Infusion or decoction in cold water.
25	*Ficus exasperata A. Chev*	Root and leaves	Gonorrhea, rheumatism	Decoction of root and leaves.
26	*Moringa oleifera Lam.*	Seeds, flowers, leaves	Fever, nutrient booster	Boiled plant parts.
27	*Cocos nucifera L.*	Fruits	Skin disorder	Extracted oil is used as a lotion.
28	*Citrus limon L. Burm.f.*	Fruit juice	Diarrhoea, ulcers, wounds, and insect bites	Rind infusion in alcohol or diluted juice, three times daily.
29	*Butyrospermum parkii G. Don*	Seed fat	Rheumatic pain boils	Oil extracted (Shea butter).
30	*Treculia africana L.*	Fruit	Rheumatism, stroke	Cooked or roasted, eaten as food.
31	*Triplochiton scleroxylon L.*	Bark	Malaria	Bark decoction.
32	*Corchorus olitorius L.*	Leaves	Dysentery, fever	Eaten fresh.
33	*Vitex doniana Sw.*	Stem bark	Dysentery	Fresh leaf infusion.
34	*Aframomum melegueta (Roscoe) K. Schum.*	Leaves, rhizomes, fruits, seeds	Abdominal pain, cold, cough, fever, and back pain	10g leaf decoction with lime, lemongrass, and mango leaves.

Plant Parts of Medicinal Plants

Figure 1 illustrates the distribution of plant parts used in the preparation of herbal remedies. The most commonly used plant part is the leaf, accounting for approximately 29%, followed by roots at 15%. Other parts, such as the nut, stem, pulp, bulb, and juice, are used less frequently, each contributing less than 10% to the total.

The predominance of leaves in herbal preparations can be attributed to their ease of collection, year-round availability, and abundance, especially given that the study area experiences rainfall for about eight months annually. This observation aligns with findings from previous ethnobotanical studies (Muthu *et al.,* 2006; Hossan *et al.,* 2010), which reported leaves as the most widely utilized plant part globally.

Moreover, harvesting leaves is more sustainable compared to harvesting roots or bark, which can harm or kill the plant. This sustainable harvesting practice supports the long-term conservation of medicinal plant species (Lulekal *et al.,* 2008; Cunningham, 2001). As such, the preference for leaves not only reflects practicality but also ecological responsibility in traditional medicinal practices.

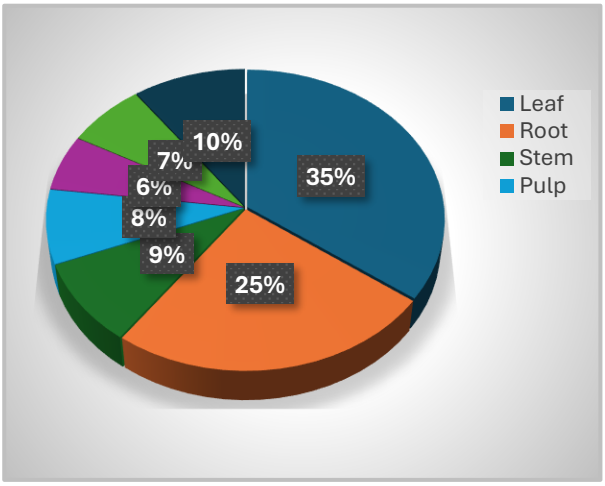

Figure 1: Percentage distribution of plant parts used

Impact of Medicinal Plants

The results in Table 4 reveal that 100% of the respondents acknowledged the positive impact of medicinal plants, particularly in reducing poverty, improving healthy living, enhancing community welfare, and reducing expenses on orthodox medicine. It indicates that medicinal plants are deeply integrated into the health and economic strategies of the respondents in the study area.

However, only 11.11% of the respondents reported an increase in income from medicinal plant usage, while a large majority (88.89%) did not associate medicinal plant usage with income generation. It suggests that while medicinal plants play a vital role in non-monetary aspects of life (health, wellness, and cost-saving), their contribution to direct economic gain is limited for most individuals in the area.

Additionally, 59.83% of the respondents noted that medicinal plants contributed to an improved standard of living, while 40.17% did not perceive any change. It further supports the argument that medicinal plants significantly contribute to quality of life, particularly through their roles in promoting affordable healthcare and enhancing family well-being

Table 4: Impact of medicinal plants on the life of the respondents in the study area

Impact	Yes (Frequency)	Yes (%)	No (Frequency)	No (%)	Total
Any impact	117	100	0	0	117
Reduction of poverty	117	100	0	0	117
Improves healthy living	117	100	0	0	117
Improves the welfare of the community	117	100	0	0	117
Reduces expenses on orthodox medicine	117	100	0	0	117
Increases income	13	11.11	104	88.89	117
Improves the standard of living	70	59.83	47	40.17	117

Medicinal Plant Marketing

Medicinal plant marketing is a profitable venture in the study area. (Table 5). On average, an individual respondent earns a gross margin of ₦398,519.20 per annum, indicating a substantial profit relative to the costs incurred.

The benefit-cost ratio (BCR) of 1.80 further confirms the economic viability of this business. This ratio means that for every ₦1 invested, a return of ₦1.80 reflects an 80 kobo gain on each naira spent. A BCR value greater than 1 indicates a profitable and efficient enterprise.

The rate of return on investment (RRI) at 72.65% and a profitability index of 42.08% underscore the attractiveness of the medicinal plant market for local respondents.

The profitability can be primarily attributed to the availability and ease of harvesting medicinal plants, which often grow freely in the environment. It reduces the cost of procurement since these plants require minimal investment for collection and maintenance. The ready availability and zero cost of raw materials make the business sustainable and attractive. These findings align with those of Sheik and Wunder (2002), who highlighted the significant role of non-timber forest products (NTFPs), such as medicinal plants, in promoting sustainable forest management and alleviating poverty.

Table 5: Socio-economic impact of selected medicinal plants in the study area (cost and return analysis per respondent per annum)

Variables	Cost (₦)	Depreciation (₦)	Depreciation (Assumed) Year
Fixed Costs			
Wheelbarrow	22,500.00	4,500.00	5
Table	2,833.33	518	5
Tray	550	122	5

Cutlass	1,950.00	378	5
Sack	660	660	5
Basket	350	350	1
Pot	2,800.00	512	5
Bowl	690	140	1
Rent	12,900.00	12,900.00	1
Other	1,120.00	1,120.00	1
Total Fixed Costs	**34,573.33**	**21,200.00**	
Variable Costs			
Cost of the product (herb)	459,000.00		
Transportation cost	12,266.67		
Association due	6,000.00		
Cost of labour	20,880.00		
Total Variable Costs	**498,149.00**		
Total Cost	**519,349.00**		
Total Revenue	**896,668.20**		
Gross Margin (GM)	**398,519.20**		
Net Income (NI)	**377,319.20**		
Profitability Index (%) (PI)	**42.08**		
Rate of Return on Investment (%) (RRI)	**72.65**		
Benefit-Cost Ratio (BCR)	**1.8**		

Conclusion

The study concludes that medicinal plants in the Osho Forest Reserve are crucial for both the cultural and economic well-being of the local communities. The widespread use of leaves suggests the adoption of sustainable harvesting practices that support plant conservation. Medicinal plants play a significant role in healthcare, poverty alleviation, and improving the standard of living in the region. Economic data confirm that marketing medicinal plants is profitable and a significant income source. However, sustainable harvesting practices and improved market access are essential to prevent resource depletion and ensure the long-term benefits of medicinal plants. Therefore, efforts to promote sustainable management and awareness of the value of medicinal plants are recommended to safeguard these resources and enhance community livelihoods.

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SOCIO ECONOMIC DRIVERS OF FOREST DEPENDENCY AND POLICY IMPLICATIONS FOR SUSTAINABLE CONSERVATION IN BENUE STATE, NIGERIA

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Abstract

Forests in Benue State serve as critical safety nets for rural households facing economic insecurity and climate stress. This study examines the demographic and economic factors influencing forest resource utilization across seven Local Government Areas, employing a mixed-methods approach grounded in the Sustainable Livelihoods Framework and the Theory of Access. Findings reveal that low income, limited education, and occupation type significantly predict forest dependency, particularly among farmers and households with limited education. Notably, the majority of respondents (73.4%) engage in farming, with nearly 50% earning less than ₦400,000 annually, conditions that drive reliance on Non-Timber Forest Products (NTFPs) for food, medicine, and income. Despite long-term residency, many households reported only recent engagement in NTFP use, suggesting a shift driven by climate-induced agricultural failures. Gender disparities in access to resources were also evident. To ensure sustainable conservation in such insecure regions, we recommend the development of integrated policy frameworks that recognize forest resources as essential components of rural livelihood resilience. It includes economic valuation of key NTFPs, investment in gender-inclusive entrepreneurship, and education-based interventions to break the povertyforest reliance cycle.

Keywords: Climate Change, Forest Dependency, Nigeria, Non-Timber Forest Products, Policy, Socio-Economic Drivers, Sustainable Conservation

Introduction

Forests are fundamental pillars supporting rural livelihoods across the developing world, providing essential goods and services and acting as crucial safety nets (FAO, 2012). Globally, hundreds of millions of people, particularly people with low incomes, rely heavily on forests for their subsistence and income needs (Chao, 2012). In Nigeria, this dependency is deeply ingrained in the socio-economic fabric of rural communities (Endamana et al., 2016), where activities such as collecting, processing, and marketing forest products are often vital livelihood strategies (Sumati, 2006). Benue State, endowed with significant forest resources including numerous reserves and communal forests (Tee *et al*., 2014), yet facing pressures from a largely agrarian population, starkly exemplifies this human-environment linkage. Local populations heavily rely on forest resources, including fuelwood, timber, medicinal plants, and various Non-Timber Forest Products (NTFPs), to meet their daily needs and supplement their income (Shomkegh *et al*., 2019).

However, this intense **forest dependency**, often exacerbated by poverty and limited alternative livelihood options, poses significant challenges to achieving **sustainable conservation**. The

increasing demand for forest resources, coupled with pressures such as agricultural expansion and population growth, contributes to forest degradation and biodiversity loss (FAO, 2006; Shomkegh *et al*., 2019). This threatens the long-term ecological integrity and the very resource base upon which local livelihoods depend. Effectively balancing the immediate subsistence and economic needs of forest-dependent populations with the imperative for **sustainable forest conservation** poses a critical policy challenge in Benue State, where forest depletion is a growing concern (Tee *et al*., 2014). Addressing this requires a nuanced understanding of *why* and *how* different households depend on forest resources.

Research indicates that **forest dependency** is not uniform but varies significantly based on **socio-economic drivers**. Factors such as age, gender, education level, household size, income diversification (particularly non-forest income), wealth status, farm size, and access to resources or markets are known to influence the extent and nature of reliance on forests (Ngalim, 2011; FAO, 2012; Shomkegh *et al*., 2019). While these general relationships are understood, there remains a critical need for context-specific evidence within Benue State. Identifying the precise **socio-economic drivers** shaping **forest dependency** locally is crucial for formulating targeted, equitable, and effective policy implications that promote **sustainable conservation** and livelihood improvement. Without this understanding, conservation policies risk negatively impacting vulnerable households or proving ineffective.

This study utilizes the Sustainable Livelihoods Framework (SLF) (DFID, 1999; Natarajan *et al*., 2022) and Ribot and Peluso's (2022) Theory of Access to investigate these dynamics. The SLF helps analyze how household asset endowments (human, financial, natural, etc.), shaped by socio-economic status, influence livelihood strategies, including the degree of **forest dependency**. The Theory of Access provides a lens to examine the complex mechanisms (beyond legal rights) that mediate different groups' ability to access and benefit from forest resources. Together, these frameworks facilitate a robust analysis of the underlying **socio-economic drivers** of **forest dependency**, providing crucial insights for anticipating the distributional impacts of potential **conservation policies**.

Therefore, this study aims to investigate the **socio-economic drivers of forest dependency** in Benue State, Nigeria, and to draw out the policy implications for sustainable conservation explicitly. Specifically, the study seeks to assess the patterns and levels of household **forest dependency** and analyze the associated socio-economic characteristics, Identify and analyze the key **socio-economic drivers** that significantly influence the degree of household **forest dependency**; and derive evidence-based **policy implications** and recommendations designed to foster **sustainable forest conservation** while concurrently supporting the livelihoods of forest-reliant communities in Benue State.

Methodology

Study Area

Benue State lies within the lower River Benue trough in the Middle Belt region of Nigeria. Its geographic coordinates are longitude 7° 47' and 10° 0' East. Latitude 6° 25' and 8° 8' North; and shares boundaries with five other states namely: Nasarawa State to the north for 231 km (partly across the Benue River), Taraba State to the east for 235 km, Cross-River State to the south for 96 km, Enugu State to the south-west for 84 km, and Kogi State to the west for 153 km and the Republic of Cameroon on the south-east. Benue occupies a landmass of 34,059 square kilometers. (Hangeior *et al*., 2024).

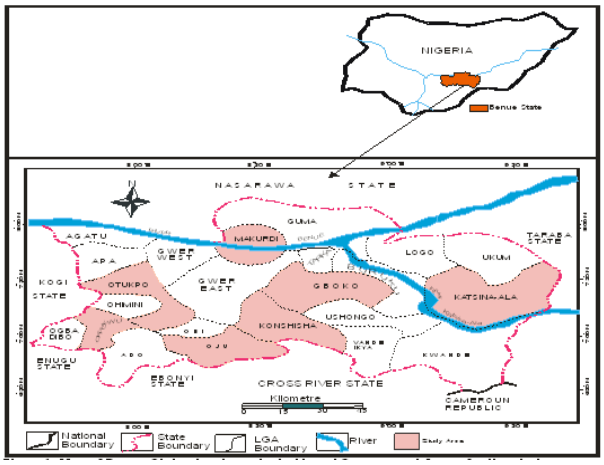

Figure 1: Map of Benue State showing the selected LGA.

Source: Ministry of Lands, Survey, and Solid Minerals, Makurdi.

Benue State exhibits a bimodal climate, characterized by a dry season from November to April and a rainy season from May to October, with a peak in rainfall observed from late July to September each year. During the dry season, temperatures reach their peak, with mean monthly maximum temperatures ranging from 39.4 °C to 30.6 °C. Conversely, during the rainy season, temperatures are comparatively lower, with mean monthly minimum temperatures ranging from 26.7 °C to 18.4 °C. Annual precipitation averages around 1238 mm, with relative humidity consistently exceeding 78% throughout the year. (NIMET, 2016).

The Savanna component consists of grasslands interspersed with Scattered Trees, which are adapted to periodic fires. The Savanna ecosystem supports a different set of plant species, including various grasses, shrubs, and Acacia trees, such as *Daniellia Oliveri, Afzelia africana, Khaya senegalensis, Vitellaria paradoxa* (Shea Tree), *Parkia biglobosa* (African Locust Bean Tree), Adansonia digitata (Baobab Tree), *Prosopis africana, Anogeissus leiocarpa.* and Grasses such as *Andropogon gayanus, Pennisetum purpureum* (Elephant Grass), *Brachiaria decumbens, Imperata cylindrica, Panicum maximum* (Guinea Grass), Shrubs like *Combretum spp, Terminalia macroptera, Detarium microcarpum*, etc.

A **descriptive survey design** was employed to investigate the demographic and economic factors influencing forest resource utilization. This design was considered appropriate because it facilitated the collection of **quantitative data** needed to describe the **socio-economic attributes** of the respondents and analyze their relationship with patterns of forest resource use. The research employed a multi-stage sampling technique, in which the state was stratified into three parts based on existing geo-political zones: Benue North-East (zone A), Benue Northwest (zone B), and Benue South (zone C). A sampling intensity of thirty percent (30%) of the Local Government Areas (LGAs) in each of the geo-political zones was done to select LGAs in each zone. Then, purposive sampling techniques were used to select LGAs. In each of the selected LGAs, 30% sampling intensity was used to select council wards. From the household population, the Taro-Yamane (1967) formula was adopted to calculate the total number of respondents for the study.

Therefore, the sample size for the study was four hundred (400) respondents.

Taro -Yamanes (1967) Method of Determining Sample Size

$$\mathbf{n}=\frac{N}{1+N(e)2} \quad \text{..... Equation (i)}$$

Where:

N = Population,

1= constant,

e = tolerable error or limit of precision,

n = sample size

$$\mathbf{nh}=\frac{n \times Nh}{N} \quad \text{..... Equation (ii)}$$

Where:

nh = number of households,

Nh = Population of households in a particular council ward

n = Sample size for the study.

N = Total household population

Table 1: Determination of Sample Size

Zone	LGAs	30% LGAs	Wards	30% Wards	No. of Households	Sampled Households
A (North-East)	7	Katsina-Ala	12	4	839	67
		Konshisha	11	3	604	48
B (Northwest)	7	Gboko	17	5	971	77
		Makurdi	10	3	472	37
C (South)	9	Otukpo	12	4	813	64
		Okpokwu	12	4	767	61
		Oju	11	3	582	46
Total	**23**	**7 LGAs**	**85**	**26 Wards**	**5,048**	**400**

Source: Adapted from Abu, G.A. (2011). Baseline Report of Fadama III in Benue State, Nigeria, Final Report, 32p

The study employed a **multistage sampling technique**. In the first stage, seven Local Government Areas (LGAs) were purposively selected based on their forest resource endowment and active community engagement in forest-related livelihoods. In the second stage, forest-dependent communities within these LGAs were randomly selected. Finally, **395 respondents** were systematically sampled from these communities, ensuring representation across gender, age, and occupation groups.

Data Collection Technique

Data were collected through the administration of **structured questionnaires**. The questionnaire comprised both closed- and open-ended questions, organized into sections covering, Socio-demographic characteristics (age, gender, marital status, education, tribe, religion, family size), eonomic variables (income level, occupation, years of experience, years of residence), patterns of forest resource utilization (type and frequency of NTFP use, motivations for use), perceived challenges in accessing, utilizing, and marketing forest products. The instrument was pre-tested with 30 respondents from a non-sampled community and refined for clarity and reliability.

Data Analysis

Data were analyzed using Descriptive statistics, including **frequencies, percentages, means, and standard deviations. Chi-square (χ^2) tests** were used to assess the associations between categorical variables (gender, education level, occupation) and forest utilization categories. **Multiple regression analysis** was conducted to determine the predictive strength of demographic and economic variables.

RESULTS

Table 1: Demographic Characteristics of Respondents in Benue State, Nigeria

Characteristic	Category	Frequency	Percent
Gender	Male	191	48.4
	Female	204	51.6
Age	18-30	49	12.4
	31-40	151	38.2
	41-50	132	33.4
	51-60	52	13.2
	61-70	11	2.80
Mean Age	41±9.178		
Marital Status	Married	305	77.2
	Single	70	17.7
	Widow	11	2.80
	Widower	9	2.30
Family Size	1-5	202	51.1
	6-10	129	32.7
	11-15	47	11.9
	16-20	15	3.80
	21-25	2	0.50
Mean Family Size	6.35±4.370		
Educational Level	Non-Formal Education	124	31.4
	Primary Education	65	16.5
	Secondary Education	137	34.7
	Tertiary Education	69	17.5
Tribe	Tiv	202	51.1
	Idoma	110	27.8

	Igede	47	11.9
	Etulo	17	4.30
	Igbos, Hausa	19	4.80
Religion	Traditionalist	17	4.30
	Christianity	378	95.7
Major Occupation	Farming	290	73.4
	Civil Service	40	10.1
	Trading/Business	32	8.10
	Fishing	2	0.50
	Hunting	14	3.50
	Student	17	4.30

Table 2: Economic Characteristics of Respondents in Benue State, Nigeria

Characteristics	Category	Frequency	Percent
Annual Income Category	₦40000 – ₦400000	196	49.6
	₦401000 – ₦800000	159	40.3
	₦801000 – ₦1200000	35	8.9
	₦1201000 – ₦1400000	5	1.3
Mean Annual Income	₦470.531.65±27954.757		
Years of experience	1-10	256	64.8
	11-20	80	20.3
	21-30	43	10.9
	31-40	15	3.80
	41-50	1	0.30
Mean Years	10.59±8.904 Years		
Years of Residence			
	4 – 20	11	2.8
	21 – 30	56	14.2

	31 – 40	143	36.2
	41 – 50	126	31.9
	51 – 60	49	12.4
	61 – 70	10	25.0
Mean Years	39.93±10.173 Years		

Table 3: Chi-Square Test and Multiple Regression Results of Association Between Socio-Economic Variables

Analysis Type	**Variables Tested**	**χ^2/F-value**	**df**	**p-value**	**Effect Size**	**Interpretation**
Chi-square	Gender × Education	28.74	3	<0.001	Cramer's V=0.27	Moderate association
Chi-square	Occupation × Education	112.57	15	<0.001	Cramer's V=0.42	Strong association
Chi-square	**Gender × Occupation**	**18.90**	**5**	**0.002**	**Cramer's V=0.22**	Weak but significant association
Regression	Income predicting forest use	F=9.87	3,391	<0.001	R^2=0.42	Income strongest predictor

DISCUSSION

The study reveals a predominantly middle-aged (Mean age=41±9.2), agrarian Population (73.4% farmers) with moderate education levels (65.2% ≤secondary education). This aligns with the **Sustainable Livelihoods Framework** (DFID, 1999), where **human capital limitations (31.4% non-formal education) correlate with higher reliance on forest resources**, as less-educated households often lack alternative livelihood options. **Gender parity** (51.6% female) masks nuanced disparities. While farming participation is balanced, hunting remains male-dominated (85.7%), reflecting the **gendered division of labor** common in West African forest communities.

The income distribution (49.6% earning ≤₦400,000/year) and regression results (β=-0.32, p<0.001) robustly support the **Theory of Access** (Ribot and Peluso, 2020). **Financial capital constraints** drive forest dependency, as low-income households lack access to alternative protein sources or energy.

The observed "experience-residence paradox," where long-term residents (Mean residency = 39.9±10.2 years) possess limited experience in Non-Timber Forest Product (NTFP) utilization (64.8% with ≤10 years' experience), suggests recent shifts in livelihood strategies. This phenomenon may be attributed to climate stressors and economic pressures prompting adaptation to new income sources. According to the Intergovernmental Panel on Climate Change (IPCC) Sixth Assessment Report, climate change acts as a risk multiplier, rendering

traditional livelihood activities untenable due to prolonged trends and sudden climate hazards such as droughts and floods. Consequently, individuals may transition to alternative livelihood strategies, including the exploitation of NTFPs, as adaptive responses to these environmental challenges (Ziervogel *et al*., 2022).

Economic constraints, exacerbated by climate impacts on agriculture and food prices, can drive households to seek alternative income sources. The IPCC report highlights that climate-induced agricultural challenges may force millions into extreme poverty, compelling affected populations to diversify their livelihoods, potentially through the collection and trade of forest resources, to mitigate financial instability.

The chi-square tests reveal that the **Education-Occupation Link** (χ^2=112.57, V=0.42). Farmers disproportionately lack formal education (78.3% with ≤ secondary education), perpetuating a **poverty-forest dependence cycle** (Angelsen *et al*., 2014). This strong association ($p < 0.001$) highlights the significant role of education in livelihood diversification. **Gender-Occupation Segregation** (χ^2=18.90, V=0.22). The weak but significant association (p = 0.002) reflects cultural norms that exclude women from hunting (Standardized Residual = 1.79 for males).Potential for gender-inclusive NTFP programs (e.g., mushroom cultivation), as seen in Cameroon (Sunderland *et al*., 2014).

Conclusion

The study revealed that household dependence on Non-Timber Forest Products (NTFPs) in Kwande LGA is closely linked to socio-economic vulnerabilities, including low educational attainment, limited income, and exposure to climate-related livelihood stressors. The predominance of farming, high reliance on forests among less-educated and low-income households, and recent shifts toward the use of NTFPs, despite long-term residency, suggest adaptive responses to worsening economic and environmental conditions. Significant gender disparities and occupation-specific roles highlight the need for inclusive approaches. To break the poverty–forest dependence cycle, there is an urgent need for integrated interventions that enhance human capital, promote gender-equitable resource access, and support sustainable NTFP utilization as a viable livelihood strategy under changing climatic and economic realities.

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SUB-THEME 7: EXPLORING THE ROLE OF GENDER ENTREPRENEURSHIP IN FOREST CONSERVATION AND MAINTAINING FOREST ECOSYSTEM HEALTH

THE USES OF RURAL ADVISORY SERVICES AS A GUIDE FOR WOMEN IN FORESTRY CONSERVATION IN NIGERIA AND ITS CHALLENGES

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ABSTRACT

The forest is the heartbeat of every home, as it significantly contributes to the livelihood of both men and women. However, women use resources from nature as a source of livelihood to generate family income in such a way that they can refer to it shortly, unlike men. Despite their efforts towards conservation, women are still not regarded as caretakers because of their fragile nature. They face various limitations, including cultural, social, economic, and security constraints. The major challenge, as reviewed in this paper, is the lack of formal education, which makes them redundant in the forest industry. This is why there is a need for rural advisory services and extension agents among the rural community, with a greater emphasis on women who depend solely on forest resources.

Key words: Women, Forest conservation, Guide, Rural advisory services

INTRODUCTION

Among several African countries, Nigeria is considered to be rich in landmass, with an area of approximately 923,775 km² or 92.4 million hectares, and a coastline that is about 960 km long (Raimi *et al*., 2019). It is a nation endowed with vast and varied natural resources, which are a function of its large geographical resources, extent, and the diversity of its natural environment. The forests in this region can be described as a reservoir for its citizens, providing a wide range of sustenance and mitigating natural hazards (Pawar & Rothkar, 2015). Its forest is rich and beautiful, full of abundant natural resources, which, if properly harnessed and managed, can sustain its rapid social and economic development (Raimi *et al*., 2019). The enormous benefits of forests are so vast that they serve as lungs to the Earth, providing carbon sinks that also provide food, fodder, and shelter. This is the primary reason for making additional efforts to conserve the forest by reducing deforestation, despite the burden it faces. The term conservation appears to be the truest and most commonly accepted meaning of the word and has always been recognized as being basic to sustained yield forestry. Truly, forests need to be conserved, protected, and preserved sustainably for future use, including plants and animal species (Pütsep, 2023). The issue of forest conservation is assumed to be gender specific because it is a

source of livelihood. Gender dimensions are particularly relevant to forest issues at the community level, and women play a key role in forest management. Studies have shown that many preconceived conceptions about female contributions to household economics and natural resources conservation, but it still appears that in most rural communities, women are at least as important as men in contributing labour, products, and income to the family. Even though women often spend the most time utilizing natural resources, they are the ones most affected by land degradation, they have little formal say in making decisions about conservation and management questions. Many say this must change if sustainability is to be achieved (Raimi *et al*., 2019).

Historically, a man has the best approach to looking after the environment. At the same time, a woman is believed to look after the home and be responsible for reproductive roles, particularly in developing countries (Juma *et al.,* 2021).In the meantime, gender is an important aspect of how and why forest resources are managed or mismanaged at the local level (Tamang *et al*., 2020). Men and women often have different roles in managing forests, knowledge about them, access to forests, and different ways of using forest resources. However, several pieces of literature confirmed that the female gender has a magnificent role in the conservation of the forest because of her genetic nature of catering to the family as well as for income generation from gathering fuelwood, medicinal plants, and other non-timber forest products, and processing secondary wood products. They have special knowledge of these precious natural resources that can provide a wide range of services when managed sustainably, rather than purely as an economic asset (Buszko-Briggs, 2022). Notwithstanding, women are still an important part of the community and the house despite the divided roles, and they play a key role in understanding their surroundings, the forest, and the services that the environment provides to the family and even the community (Hudgson, 2014).Women work tirelessly in the informal economy and are relegated to lesser pay than men. More often, they have little say in decision-making that concerns their forests, and their contribution is not appropriately documented (Buszko-Briggs, 2022). Much of this negligence can be attributed to low representation of women in forest management and development due to educational, traditional, social, cultural, religious, technological, and economic factors, and the inaccessibility of forestry extension services (Agbogidi et al., 2004). If the forest were to disappear, women, particularly the rural ones, would be even more vulnerable. This is why they must be involved and educated on forest management with the help of an extension officer. This paper aims to review the role of women in forestry, the challenges faced by this gender, and the role of extension services in educating them.

THE ROLE OF WOMEN IN FORESTRY CONSERVATION

The earth is intimately connected with indigenous culture, which an indigenous woman cannot disconnect from; it symbolizes “Mother” because it offers its inhabitants all the resources necessary for their existence and survival. Mother Earth is known to be benevolent as it provides forests, rivers, and a diverse range of flora and fauna, many of which are useful for medical or technological purposes, contributing to a better quality of life (Raimi *et al.,* 2019). For this reason, women in the developing world often assume the role of “caretaker” for their families as well as for the other people and things around them (Pinchot Institute for Conservation, 2006). They are recognized to play a key role in the management of forests and forest products. They have traditional knowledge of forest rehabilitation activities, managing forestry products, and improved forest governance, including executing management plans (Azeez et al., 2013; Stiem & Krause, 2016). Across sub-Saharan Africa, women’s management practices involve their support to lives, livelihoods, and households (WRI, 2020). One of their management practice

centers around forest, especially poor women in rural areas who have a greater stake in forest rehabilitation and management because it contribute to their livelihood from the collection and sales of forest products such as vegetables, fruits, soup condiments, staking materials, fodder, fuel wood, medicinal herbs, and other products for sponge, basket weaving, brooms, and rattans (Agbogidi *et al*., 2003). Thus, the current gendered approach to forest management puts women on the margins, as it affects the success of forest management goals, as their knowledge is very crucial on focusing on forest products linked to family well-being, food production, energy use and conservation practices, as well as health (Lingam, 2023). Some scholars believe that women are critical actors in managing forest resources simply because their participation in sustainable forestry management is conditioned by their levels of forest dependence (Nuggehalli & Prokopy, 2009). As a result of gender division of work, women primarily gather a wide range of NTFPs for subsistence and as a source of income, while men are largely involved in timber extraction (Pandofelli, Meinzen-Dick and Dohrn, 2009). For example, African Shea (*Vitellaria paradoxa*), *Parkia biglobosa* seeds, *Chrysophyllum albidum* fruits, *Adansonia digitata* leaves and fruits have long been collected, processed, and traded by Nigerian women; this has been their main source of income. Women also contribute to the forest sector through agroforestry, watershed management, tree improvement, and forest protection. They make a significant proportion of the labour force in forest industries, especially in tree nursery work (FAO, 2016), because they are often burdened by the disappearance of tree species, as it would affect their food security. Invariably, women adopt environmentally friendly farming system practices such as terracing and taungya cultivation of fodder trees and campaign against free grazing in community forests, to lower pressures on forests. For instance, women living around the Olokemiji forest reserve in Nigeria tend to adopt agroforestry practices (Acharya and Gentle, 2006). One recent study found that forest patches managed by women had 51% less deforestation than those managed by men, and over 80% of the world's remaining forest biodiversity is within the lands of indigenous women who have protected them for generations (Self, 2024). For example, in Cross River State, Nigeria, women successfully resisted men's alienation of large forest blocks from whose ranges they gather many NTFPs that constitute the bulk of their families' means of subsistence and income generation (Johnson 2003). Similarly, village women from Nigeria's Cross River State have been engaged in community-based REDD+ actions for a decade and have been recognized as a forest stakeholder group that should benefit from the investment plan. They were also involved in the design and validation of the plan and will play an important role in the implementation of strategies to mitigate climate change (UNDP,2022). In addition, recent research from Areo *et al* (2024) has shown that even urban women in Nigeria are now considerably represented in the wood plank marketing business. Women play various roles in forestry, including work, processing, and community management, contributing significantly to the economy through logging, timber production, and community forestry initiatives. They add value to raw timber products during processing, and many operate small-scale timber businesses, overseeing the procurement, processing, and retailing of timber products. Additionally, women involved in forest management often participate in community-based projects like reforestation, conservation, and sustainable resource management, where their leadership can influence broader forest policy and management strategies (Areo *et al*., 2024). Women also have specialized knowledge of trees and forests in terms of their species diversity. Women conceive of nature, biodiversity, and knowledge holistically, within a territory that must be defended and preserved for the good of humanity as a whole. Also, women's participation and decision-making in the management of local

forests significantly improve forest conditions and conservation despite facing numerous barriers and challenges**.**

CHALLENGES INVOLVED IN WOMEN'S PARTICIPATION IN FOREST CONSERVATION

The rural woman largely contributes to the Nigerian rural economy to sustain urban food security, but their role is unnoticed and inconsequential. Often they are marginalized in terms of cultural and social barriers, which limit their access to land for farming, face inequalities around customary systems with tenure rights, and are always in favour of male members of the communities. This makes it difficult for women to contribute effectively to food security and sustainable natural resources management. This rural population accounts for 60% of the Nigerian population, who are vulnerable to economic shocks and the deterioration of natural resources. They are the ones involved in most value chain activities in the world of agriculture, agroforestry production systems, and have learnt to manage these resources to preserve them for future generations. Yet, they are denied access to and control of these resources (Pearl, 2003), and they suffer most from environmental disasters, which reduce forest products. Despite their significant roles in the conservation process of forest resources, they frequently encounter obstacles such as limited decision-making power, restricted access to land ownership, and insufficient training and resources (FAO, 2018).

They are the most vulnerable in the community and rarely have access to resources that would lessen their burden, such as fetching firewood, food, fruits, and meat, even to the extent of processing it when they get home. Unfortunately, they are often engaged with a double work burden of heavy domestic and child-rearing responsibilities, and they engage their children in these rigorous activities, which hold them back in public engagement or participation in essential duties in the communities (Engida & Mengistu 2013, Musyoki et al. 2013, Tadesse et al. 2017). In addition, is the issue of insecurity which has ravaged the Nigeria's forest and complicated issues for the rural women making them feel disadvantaged in accessing forest resources compared to men due to the lack of transport and safety concerns; in contrast, young women are discouraged from going to the forest alone due to fear of sexual harassment.

Also, in some forestry operations and other departments, women are employed along with men but some traditions, taboos, and beliefs consider them to be inferior to men in making decisions on their rights to forest and tree products, and this restrict them to little profit or commercial benefits (Gera, 2002; Mhache, 2018). Mbogori (2014) stated that lack of formal education is the main factor of these challenges has it leads to poverty, assaults such as rape and discrimination, and deprives them of many benefits like credit and technology, as well as rights to family wealth and inhibits their ability to influence resource allocation or research. This layback often puts rural women at the rear or excludes them from stakeholder meetings in most communities. Consequently, decisions and policies on forest issues are usually not favourable to them at the household, community, and national levels which is attributed to low representation of women in forest management and development due to educational, traditional, social, cultural, religious, technological, and economic factors, and the inaccessibility of forestry extension services (Agbogidi et al., 2004).

THE ROLE OF RURAL ADVISORY SERVICE IN WOMAN PARTICIPATION IN FOREST CONSERVATION IN NIGERIA

These days, the role of extension services is multifaceted as extension agents are expected to have a general knowledge about agriculture, which includes fisheries, crops, livestock, and forestry (Adedokun *et al,* 2021). Extension

services, also known as rural advisory services, provide different information, guidance, services, and activities that farmers and other rural actors need to develop their knowledge, skills, and practices and improve their livelihoods (GFRAS 2012). By promoting sustainable forest management practices, extension forestry programs contribute to the conservation, restoration, and utilization of forests in a manner that ensures their long-term viability and benefits. Nevertheless, Manfre *et al.* (2013) stated that the failure of these services has not adequately served women farmers. Forests cannot be protected and conserved unless extension officers demonstrate to the local people that they can make a reasonable livelihood from the forests on a sustainable basis (Agbogidi & Ofuoku, 2009). This can be achieved by communicating with and educating the people about the protective measures of the forest through extension. It enables rural people, especially women, to know that forests will be better enjoyed by sharing their benefits if sustainably managed (Agube *et al*., 2021). Extension services are not only necessary for forest protection, as it is suitable to empower women, especially the rural dwellers, to understand that the widespread harvesting of trees for fuel burning and the clearing of land for agriculture and cattle raising leads to the destruction of tropical rainforests. Several studies have shown that women have lower access to extension officers than men (Kiptot & Franzel, 2012), which denies them access to vital information about their environment. Also, Myae (2024) deduced that women lack awareness of their rights in community forestry, which extension can assist with by increasing their knowledge to improve their activities, and consciously doing things right. By so doing, forestry extension contributes to social development, homemaking, and youth development and subsequently, poverty reduction (Ekpere and Durant, 1999; Eke, 2001; Reid *et al*., 2006). Agbogidi and Ofuoku (2005) maintained that forestry research is a veritable instrument for food security and environmental protection and conservation because, according to them, investment in forestry research has a multiplier effect and can improve the lives of the young rural people by providing job opportunities and other services. With forestry extension, rural women will be sensitized on how to plant and conserve natural trees to provide them with valuable crops and timber, soil conservation, crop shade, wind breaks, wildlife habitats, secure food availability, and livelihood (Agbogidi & Ofuoku, 2009). In the same way, forest extension enables the rural women to recognise that the economic viability of the forest sector is a prerequisite to safeguarding the environmental, social, and cultural functions of the resources (Adedayo *et al.,*2010). Also, existing and emerging scientific knowledge about sustainable forest management practices needs to be communicated to all forestry stakeholders through forestry extension if the present alarming and increasing rate of deforestation and forest degradation is to be reduced in the forest zones of Nigeria (Igbokwe,*et al,* 2021).

CONCLUSION

Forest conservation is considered to be gender bias because of the different roles played by the two actors. The male gender is mostly interested in income derived from the forest, while the female gender is concerned about its contribution to family diets and welfare. Forest, however, cannot regenerate by itself unless there is adequate provision for it. Women's contribution to forest conservation can be traced to their mothering nature in the family and society. It reveals that women indirectly preserved forest resources a long time ago through indigenous knowledge on the collection and sales of forest products, and also participate in agroforestry practices unknown to them since they are the main labour force in agriculture in Nigeria. They are faced with several challenges within the forest communities, such as cultural, social barriers, and so on, which make it impossible for them to contribute immensely to forest development. Through the intervention of an extension agent, this paper reveals that rural

women will be privileged to have a better understanding of forest conservation practices.

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Theme: *Forest Sustainability in the face of climate change and insecurity: Innovative technologies and Strategies*

ASSESSMENT OF FARMING TECHNOLOGIES ADOPTION AND GENDER AMONG COCOA FARMERS IN OSUN STATE, NIGERIA.

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Abstract

Agricultural technology is the key engine of growth in agriculture. However, there is recognition that gender disparity exacerbates the impediments to unequal agricultural incentives and technology adoption, despite their critical roles in enhancing agricultural performance. This paper assessed the adoption of farming technologies and the the gender nexus as applied to cocoa farmers in Osun State, Nigeria. A multi-stage sampling technique was employed for the selection of ninety-four (94) respondents with 47 male and female cocoa farmers each. Questionnaires were administered to collect a set of cross-sectional data, which were then analyzed with descriptive statistical tools and fractional probit regression. The findings revealed significant gender disparities in technologies adoption with male-headed farmers exhibiting higher rate of adoption of improved cocoa varieties, agrochemicals and mechanization as compare to female. The average rates of technologies adoption given by 81% to 72% indicated a substantial gap within male and female cocoa farmers respectively. Female-headed farmers faced considerable constraints, including limited access to credit, farm training, and information, which hindered their adoption of technologies. Also, technologies adoption rates influenced by extension visits, farming experience, cocoa farmers' association, land ownership, challenges of inadequate knowledge and pest invasion. In conclusion, the study found that the adoption of cocoa technologies is widespread among farmers; however, males adopt more technologies than their their female counterparts. Socio-economic and farm-level variables like extension aids, farming experience, farmers' association, land ownership, poor knowledge and pest invasions significantly determined technologies adoption among cocoa farmers. It recommended institutional assistance, social networks, and field training to support the adoption of agricultural technologies among cocoa farmers, irrespective of gender.
Keywords: Gender, farming technologies, adoption, cocoa farmers, Osun State.

Introduction

Cocoa tree (*Theobroma cacao species)* is continually being the most economic potential and valuable cash crop in Nigeria (Awoyemi and Aderinoye-Abdulwahab, 2019; Kongor *et al.,* 2024) as Nigeria ranked fourth among cocoa producing countries throughout the world. Cocoa is a vital income earning produce for thousands of small, medium and large scales farmers thereby, contributing to households' livelihoods and gross domestic product GDP in agricultural sector.

In countries like Nigeria, Ghana, and Côte d'Ivoire, cocoa farming sustains local communities, meets international market demand, and remains a primary source of livelihood for many households (Afolayan, 2020; WCF, 2020). Recently, cocoa plantations gained prominence among other export commodity crops in terms of revenue earnings per year in this country. It has shifted its benefits to the supply side this time around and, as a result, attracted many men and women among farmers in southwestern Nigeria,

with its vast economic returns. In essence, for Nigeria today, cocoa cultivation has grown rapidly in the southwest regions as a result of an upward shift in price from N90,000 to ₦480,000 per bag (60kg). Cocoa output has also increased from an annual output of 225,000 tons in 1999 to approximately 350,000 tons in 2019 (FAOSTAT, 2021).

Notwithstanding, cocoa farming is still managed under traditional methods, yet it is one of the leading agricultural products in Nigeria and supports the country's economy in several ways. Cocoa plantation, as one of the important export crops, deserves proper management and good agronomic practices at all stages. Cocoa cultivation requires specific climatic conditions, including high humidity, consistent rainfall, and a temperature range of 21–32°C. Cocoa trees begin producing pods around the 3rd to 5th year after planting. Each tree produces 20–30 pods, each containing 20–50 seeds (beans). Agricultural technology development is a crucial strategy for enhancing productivity among farmers (Oyewole *et al.,* 2023).

Agricultural technology is the key engine of growth in agriculture inclusive cocoa cultivation however, poor state of agricultural technologies adoption is the most challenging constraint faced the Nigerian agricultural development at the moment. Agricultural technologies encompassing all improved techniques and equipment that led into positive changes or trends in the growth of agricultural output (Jain *et al.,* 2009).

Technologies in cocoa production include improved planting materials, pest and disease management techniques, fermentation and drying equipment, solar power installations, mechanized plant harvesters, modern storage methods, and information and communication technologies (ICT) for better farm management and market promotion. Additionally, technologies such as precision agriculture tools, including remote sensing and GIS, enable farmers to monitor crop health and optimize input usage, resulting in increased productivity. Thereby, improved agricultural technologies adoption (both conventional and innovation farming practices) cannot be underscored for good performance of cocoa production in Nigeria (Kongor *et al.,* 2024).

It is worth noting that women farmers are central to the sustainability of the cocoa supply chain and cocoa-growing communities. The understanding of this is supposed to promote the adoption of improved agricultural technologies, irrespective of gender, which consequently accelerates growth in cocoa cultivation and potential yields. According to Awoke *et al.* (2025), women who comprise 43% of the agricultural labor force are particularly vulnerable due to gender inequalities, especially in African societies.

In addition, previous studies have shown that the uptake of new and better technologies for cocoa production among farmers differs depending on factors such as gender, resource endowment, and level of information on existing technologies. Gender differences in agriculture, especially in innovation adoption, have been observed among many farm communities.

The negligence of women's engagements and presence in the agriculture is limiting opportunities to their sides and it further escalates the impediments of unequal agricultural incentives and technologies adoption despite their critical roles in enhancing agricultural performance.

Against this background, this study aims to explore the following research questions in an attempt to address agricultural gender bias in the context of farming technology adoption in cocoa production.

i. Did the rate of technology adoption in cocoa farming differ by gender in the study area?

ii. What factors determine technology adoption among cocoa farmers on a gender basis?

iii. What are the specific barriers faced by male and female-headed cocoa farmers in the adoption of technologies in the study area?

Methodology

The study was conducted in Osun State, Nigeria. The state is located in southwestern Nigeria, including other states such as Ondo, Ekiti, Oyo, Ogun, and Lagos. This region enjoys a tropical

climate, with two distinct seasons: the rainy season, which spans from April to October, and the dry season, which is from November to March. It has a relatively high amount of rainfall, averaging 1,200 mm – 2,000 mm annually, which often leads to the growth of crops, including cocoa, which prefers areas with many humid rainfall periods. The temperature in the state is approximately 25°C to 32°C, offering the required heat for cultivating a multitude of crops, including cash crops such as cocoa. Due to fairly evenly distributed rainfall and moderate temperatures, the climate is very favorable for farming. The area falls within the rainforest zone of Nigeria, which has vital ecosystems and well-preserved vegetation resources (NEST, 2016).

A multistage sampling technique was used to select 94 respondents for the study. Firstly, the Ife Agricultural Development Programme (ADP) in Osun State was considered a prevalent place for cocoa farming, and secondly, Ife-East Local Government Area was purposively selected as one of the major areas where cocoa trees thrived well. During the third stage, the list of registered cocoa farmers was obtained from the records section at the agricultural zonal office located in Osun State. Lastly, a sample size of ninety-four (94) respondents was randomly sampled by the proportional sampling approach adopted by Cochran (1977).

The data collection was based on a cross-sectional survey using a structured questionnaire and interview schedule. Descriptive statistics, including frequency, mean, percentage, and fractional probit regression, were adopted to analyze the data collected from the sampled cocoa farmers.

Fractional probit regression was estimated to examine the factors determining technology adoption among cocoa farmers on a gender basis. The analysis is a statistical technique used to model a dependent variable that represents a proportional or fractional outcome, whose values are bounded between 0 and 1. This approach is beneficial when the outcome variable takes on values between 0 and 1 (such as a percentage or a probability), but it does not necessarily take only binary values, unlike typical probit or logistic regression. It is similar in approach to the Tobit regression model, but the case of truncated outcome variables does not occur. Specifically, the basic form of the fractional probit regression model is:

$$yi=f(Xi\,\beta)+\mu i$$

Where yi is the unobserved latent variable, Xi represents the vector of independent variables, β is a vector of coefficients to be estimated, μi is the error term, and it is assumed to follow a standard normal distribution. Key variables included are the adoption rate of agricultural technologies as the dependent variable, whereas other variables, such as extension contacts, farming experience, membership in a cocoa farmers' association, land ownership, access to training, challenges related to inadequate knowledge, and pest invasion, were included as explanatory variables (Table 1). The test of multicollinearity at (p=0.05) was performed on the model to eliminate the problem of multicollinearity that commonly happens in cross-sectional data analysis (Shrestha, 2020)

Table 1: Description and Measurement of Variables

Variables	Expected signs	Measurement
Dependent variable: adoption rate of agric tech	+	Ratios/fractions
Independent variables:		
Extension contacts	+	Dummy (1 = yes, No= 0)
Farming experience	+/-	Continuous (year)
Cocoa farmers' association	+	Dummy (1 = yes, 0 otherwise)
Ownership of farmland	+	Dummy (1 = yes, 0 otherwise)
Access to training on farm technologies	+	Dummy (1 = yes, 0 otherwise)
Number of cocoa trees	+	Continuous (count)

Challenge of inadequate knowledge	-	Dummy (1 = yes, 0 otherwise)
Pest invasion	-	Dummy (1 = yes, 0 otherwise)

Source: Survey work, 2024

Results and Discussion

3.1 Cocoa Varieties Selected for Planting

Table 2 shows the distribution of cocoa farmers based on the selection of different cocoa varieties. The Trintario cocoa variety was among the varieties available and well known to farmers, and it is widely propagated, as shown by the proportions of male and female-headed farmers who planted it. It was reported that 40.43% and 36.17% of female and male cocoa farmers selected the Trintario variety, while the pooled result revealed that 38.30% of the cocoa farmers planted it. Additionally, the next variety of cocoa in cultivation observed is the T-series cocoa variety, comprising 34.04% of male-headed farmers, with pooled respondents of 31.91% and 29.79% of female-headed farmers who planted it. Amelondo variety is also a prevalent cocoa type planted by male farmers, comprising 19.15%, female-headed and pooled farmers, consisting of 21.28% each. However, as indicated in Table 2, the rest of the two varieties, including Foretero and Olorun funfun cocoa types, were not widely known in the study area. This result signified that most cocoa farmers have an interest in both Trintario and T-series varieties than in other types, which may be a result of their resilience to weather as well as their productivity.

Table 2: Distribution of Cocoa Farmers by Varieties of Cocoa Selected for Planting

Cocoa Varieties	Male-headed		Female-headed		Pooled	
	Freq	%	Freq	%	Freq	%
Amelondo	9	19.15	10	21.28	20	21.28
T-series	16	34.04	14	29.79	30	31.91
Trintario	17	36.17	19	40.43	36	38.30
Foretero	5	10.64	2	4.26	7	7.45
Olorun funfun	0	0.00	1	2.13	1	1.06
Total	47	100	47	100	94	100

Source: Field Survey, 2024

Adoption of technologies by cocoa farmers

Table 3 specifies the distribution of cocoa farmers by their adoption of good agricultural practices in growing the tree. From the distribution, it was discovered that a substantial percentage of cocoa farmers, both male (100%) and female (89.36%), responded positively to the adoption of technologies. The high percentage distribution of about 95% in the case of the pooled farmers underscored the growing recognition of the importance of adopting cocoa farming technologies to enhance cocoa yields and farm sustainability.

Table 3: Distribution of cocoa farmers by responses to technology adoption

Cocoa technologies adoption	Male-headed		Female-headed		Pooled	
	Freq	%	Freq	%	Freq	%
Yes	47	100.00	42	89.36	89	94.68
No	0	0.00	5	10.64	5	5.32
Total	47	100	47	100	94	100

Source: Field Survey, 2024

Different essential cocoa technologies adopted by cocoa farmers

The statistical distribution shown in Table 4 revealed that farmers are proactive in their

adoption of certain cocoa farming technologies as noticed in the usage of right dosage of agrochemicals comprising (85.11%) for pest and disease control among male -headed, sanitary harvesting and pods storage as indicated by harvesting of the ripen pods and removal of diseased pods from the lots (100.0%), and use of correct objects (blunt) to break cocoa-pods (80.85% and 76.60%) for male and female-headed farmers respectively. Also, cocoa farmers are attentive to fermentation and drying processing as observed from their activities such as quick breaking of cocoa comprising (100.0%, 95.74%), ferment right after pods breaking (91.49%, 87.23%), sun drying (for 7 to 14 days) consisting of (93.62%, 87.23%) male and female- headed respectively. All of these farming techniques raised in this study and some other have good weight in maintaining cocoa quality produce. In addition, there is significant exercise of segregating cocoa beans in to sizes and packing the cocoa beans in jute bags for storing. Overall, there is a notable gender difference in the distribution as reflected in the result (Table 4), this is evident by the average rates of technologies adoption given by 81% to 72% for the male and female farmers respectively. It further highlights challenges female farmers face in accessing appropriate farming technologies.

Table 4: Distribution of cocoa farmers by technologies adopted (n=47 each)

Cocoa farming technologies	Male		Female	
	Frequency	%	Frequency	%
Pest &Disease Control Practices				
Fungicide application	20	42.55	28	59.57
Insecticides application	30	63.83	27	57.45
Use of approved fertilizers	27	57.45	25	53.19
I apply the right dosage	40	85.11	30	63.83
Harvesting and Pod Storage				
Harvesting just-ripened pods	43	91.49	40	85.11
3–4 days harvesting interval	41	87.23	40	85.11
Removal of diseased pods from the lots	47	100.0	45	95.74
Sanitary harvesting	47	100.0	46	97.87
Pod storage (in heap for 2-3days)	33	70.21	28	59.57
Pod breaking and bean removal				
Use blunt objects for pod breaking	38	80.85	36	76.60
Removal of defective beans	28	59.57	22	46.81
Fermentation and drying				
Quick breaking of cocoa pods	47	100.00	45	95.74
Ferment right after pod breaking	43	91.49	41	87.23
6 days of fermentation with 2 turnings	41	87.23	40	85.11
Draining of sweat	40	85.11	38	80.85
Sun drying for 7 to 14 days	44	93.62	41	87.23
Covering readiness against rain	38	80.85	35	74.47
Frequent stirring and polishing	40	85.11	38	80.85
Removal of defective beans/debris	40	85.11	38	80.85
Storage				
I sieve to segregate cocoa beans according to size	43	91.49	39	82.98
I store cocoa on the gratings	40	85.11	28	59.57
I bag cocoa in jute bags	37	78.72	45	95.74
I store only cocoa in the place/room	28	59.57	35	74.47
I fumigate cocoa immediately on storage	38	80.85	29	61.71

Source: Field Survey, 2024 ***** Multiple responses

Factors influencing technology adoption in cocoa farming by the fractional probit model

Table 5 presents the results of the fractional probit regression analysis, which examined factors determining technology adoption among cocoa farmers in the study area. The dependent variable in the analysis is rate of technologies adoption, captured by considering those technologies adopted out of available technological options. In contrast, the statistically significant independent variables included extension visits, farming experience, membership in a cocoa association, ownership of land, training attended, number of cocoa trees, challenges of inadequate knowledge and pest invasion.

Specific challenges, such as inadequate technical knowledge ($p = 0.01$) and pest invasion ($p = 0.05$), were found to determine the adoption rate of cocoa technologies in both cases. Specifically, this result shows that with the increased challenge of inadequate knowledge, it is likely that farmers will lose hope in adopting available technologies, especially if there is no one to train them. It is due to a significant inverse relationship between the adoption rate of technologies and the challenge of inadequate knowledge of the technology in both genders. But, in the case of pest invasion problem, it was observed that an increasing rate of pest attack on the fields will eventually lead to more adoption of farm technologies because of a positive coefficient and significant at the ($p= 0.01$) level. These positive coefficients indicate that as the threat of pest invasion increases, farmers are more likely to adopt technologies to protect their crops. It suggests that pest control is a significant motivator for technology adoption, as farmers seek to mitigate the risk of crop losses due to pest invasions.

For male farmers, the frequency of extension visits is a highly significant predictor of technology adoption at the 1% level. The positive coefficient indicates that more frequent visits by extension officers significantly boost the likelihood of adopting new technologies. This suggests that male farmers derive significant benefits from access to expert advice, guidance on best practices, and information dissemination facilitated by extension services. Awoyemi and Aderinoye-Abdulwahab (2019) also ascertained this.

Farming experience is a significant determinant of technology adoption for female farmers at the 5% level, with a positive coefficient meaning that as female farmers accumulate more years of experience, their likelihood of adopting technologies increases. It suggests that seasoned female farmers may become more confident in their ability to implement new farming practices effectively.

Being a member of a cocoa association significantly influences the adoption of technologies by female farmers at the 5% level. The positive coefficient indicates that membership in a farmer association provides women with access to shared knowledge, group training, and possibly collective bargaining power, which enhances their adoption of improved technologies.

Land ownership is significant at the 5% level for male farmers, with a positive coefficient (0.20090). It suggests that male farmers who own their land are more likely to adopt new technologies, possibly because land ownership provides security and an incentive to invest in long-term improvements. Secure land tenure enables farmers to take calculated risks, knowing they will reap the benefits of their investments in the future

Table 5: Fractional probit result showing factors influencing the adoption of technologies in cocoa

Independent variables	Male-headed Coefficient (Std. Error)	Z-value	Female-headed Coefficient (Std. Error)	Z-value
Extension visits	4.42292 (0.18449)	23.97***	0.23122 (0.17379)	1.33
Farming experience	0.00452 (0.00700)	0.65	0.01186 (0.00565)	2.10**
Cocoa association	0.03043 (0.12551)	0.24	0.28812 (0.11770)	2.45**
Ownership of land	0.20090 (0.08294)	2.42**	0.07602 (0.12512)	0.61
Attend trainings	0.08097 0.09141)	0.89	-0.01830 (0.08213)	-0.22
Number of cocoa trees	0.00053 (0.00032)	1.63	0.00041 (0.00026)	1.53
Inadequate knowledge	0.69571 (0.17685)	-3.93***	0.40246 (0.19119)	-2.10**
Pest Invasion	0.62062 (0.15041)	4.13***	0.44384 (0.18006)	2.46**
Constant	-4.13960 (0.53223)	-7.78	-0.04433 (0.27332)	-0.16
Pseudo R^2 = 0.0460				
Prob > chi^2 = 0.0000				

Source: Field Survey, 2024 (** denotes 5% significance level, *** denotes 1% significance level)

Constraints faced by cocoa farmers in the study area

Table 6 outlines the major constraints faced by both male and female cocoa farmers in the study area. These challenges directly impact their ability to successfully adopt and implement farming technologies as well as vital and good agronomic practices.

The most frequently cited constraint, affecting 68.09% of the farmers, is the lack of credit to purchase improved cocoa varieties. Access to finance is critical for adopting modern agricultural technologies, including improved seeds or seedlings. Farmers often struggle to secure the necessary funds due to restrictive lending conditions, high interest rates, or inadequate financial infrastructure (Badiru et al., 2023). Pest invasion ranks as the second most pressing issue, affecting 65.96% of the farmers. Pests such as capsids and cocoa mirids cause significant damage to cocoa trees, resulting in reduced yields and quality. Pest infestation increases the cost of production due to the need for pest control measures, such as insecticides. It can discourage farmers from fully adopting new technologies that require stable environmental conditions to succeed. Awoyemi and Aderinoye-Abdulwahab (2019) raised similar negative effects of pests and diseases on the cocoa crop

Poor pricing of cocoa, affecting 61.29% of the farmers, is a market-related challenge that reduces the incentive for farmers to adopt new technologies. When cocoa prices are low, farmers have less motivation and fewer resources to invest in improved practices and technologies. Inadequate knowledge, cited by 53.19% of the farmers, is a significant constraint on technology adoption. Many cocoa farmers lack the technical expertise required to implement advanced agricultural practices. The absence of sufficient extension services and training programs exacerbates this issue, leaving farmers without the necessary skills to make informed decisions about the use of technology and farm management.

Disease infestation, including conditions such as swollen shoots, affects 51.06% of the farmers.

Cocoa diseases can devastate plantations, causing significant yield losses and threatening the long-term viability of farms. Effective disease management often requires specialized knowledge and access to disease-resistant varieties, both of which are limited for many farmers in the study area.

Another constraint, low cocoa quality, is faced by 51.06% of the farmers. Poor-quality cocoa can lead to lower market prices, further exacerbating the financial challenges farmers face. This issue is closely tied to the adoption of GAPs, as many of the recommended practices aim to improve cocoa quality. However, without the necessary knowledge, resources, and support, farmers struggle to meet quality standards, limiting their access to premium markets. Climate change-related challenges, affecting 50.00% of the farmers, are another significant barrier to technology adoption. Changes in rainfall patterns, increased temperatures, and extreme weather events make it difficult for farmers to plan and manage their crops effectively.

Theft of cocoa beans and farm inputs is a concern for 47.87% of the farmers. This issue discourages investment in farm improvements, as farmers fear losing their produce or equipment to theft. The insecurity caused by theft also reduces farmers' confidence in adopting new technologies, as they may not be able to protect the returns on their investments fully. Chemical damage, reported by 45.74% of the farmers, refers to the unintended adverse effects of agrochemicals, such as pesticides and fertilizers, on cocoa trees. Improper application of chemicals can harm crops and reduce yields, leading to a reluctance among farmers to adopt new chemical technologies. Fire outbreaks, affecting 41.49% of the farmers, are another environmental constraint that hinders technology adoption. Fires can destroy entire plantations, wiping out years of investment and labor. Generally, Awoyemi and Aderinoye-Abdulwahab (2019) and Thomas *et al (*2022) have previously identified some of these constraints as typical issues in cocoa farms.

Table 6: Distribution of Cocoa Farmers by Constraints Faced

Constraints	Frequency	Percentage (n=94)
Credit to purchase improved varieties	64	68.09
Pest invasion	62	65.96
Poor pricing of cocoa	57	61.29
Inadequate knowledge of the farmers	50	53.19
Disease infestation e.g, swollen shoot	48	51.06
Low cocoa quality	48	51.06
Climate effects	47	50.00
Theft	45	47.87
Chemical damage	43	45.74
Fire outbreak	39	41.49

*Multiple choices Source: Field Survey, (2024)

Conclusion and Recommendations

Based on the findings of this study, it was observed that technologies adoption in cocoa farming is widespread among both male and female-headed farmers in the study area, although gender imbalance exists in the adoption rates of technologies.

Despite these gender-specific dynamics, it is clear that both male and female cocoa farmers are keen on adopting technologies that improve productivity. However, they face similar challenges such as lack of access to credit, poor pricing, and pest infestations. The study therefore, highlights the important drivers of technologies adoption rates among the farmers as included extension visits, farming experience, cocoa farmers' association, land ownership, challenges of inadequate knowledge and pest invasion.

Invariably, the study advocates for a continuous adoption of farming technologies in cocoa plantation irrespective of genders. Hence it recommends farmers' experience/knowledge, field trainings by extension workers, membership in association, land ownership coupled with diseases/pests controlling for improving rate of cocoa technologies initiatives throughout the study area as well as other cocoa producing states.

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CONSTRAINTS HINDERING WOMEN'S INVOLVEMENT IN AGROFORESTRY IN AKINYELE LOCAL GOVERNMENT AREA, OYO STATE

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Abstract

Agroforestry involvement is the act of participating in agricultural activities, which include farming practices such as plowing, tillage, cropping, and the installation of best management practices, as well as harvesting for the the production of food and fiber products. Therefore, this study investigates the Constraints hindering women's involvement in Agroforestry in Akinyele Local Government of Oyo State. Eighty (80) respondents were selected from the study area using multi-stage sampling techniques. A well-structured questionnaire was used to obtain the data. Data collected were subjected to descriptive statistical analysis to measure mean and percentage, while inferential statistics, such as PPMC, were used to measure the relationship between variables. The results revealed that the majority of the respondents are married, above 50 years of age, with a secondary education background, and a household of less than 5. Also, shows that the majority of the respondents are involved in shifting cultivation, wind break, taungya, and fuel wood production as agroforestry practices in the study area.

Furthermore, the analysis revealed that the majority of respondents had a level of involvement in all agroforestry practices once a year. Also revealed that the majority of the respondents had reservations about storage and processing facilities, disease and pest infestations, and a lack of finance (capital and credit) as mild constraints in the study area. However, the results also revealed a significant relationship between constraints and the level of involvement in agroforestry practices in the study area. It is therefore recommended that awareness and encouragement of young women farmers to get involved in agroforestry to enhance Agricultural production as a whole.

Introduction

Agrororestry practices also play a critical role in global climate regulation as forest trees absorb carbon dioxide, a greenhouse gas believed to be responsible for global warming. Plants naturally absorb carbon dioxide and give out oxygen in the process of photosynthesis. Tropical rainforests absorb more carbon dioxide than any other terrestrial ecosystem on Earth. There is general

agreement among the scientific community that by absorbing some of the gas, rainforests play a Vital role in lessening its impacts. Efforts have been made over the years to ensure that farmers adopt improved agroforestry practices, thereby reducing some of the environmental and economic challenges they face. UNEP 2015). Agroforestry is significant in the production of both local commodities (such as fuel wood, timber, fruit, and fodder) and global ones (Such as coconut, coffee, tea, cocoa, rubber, and gum). It can also play a strategic role in helping many countries meet key national development objectives, especially those related to poverty eradication, food security, and environmental sustainability. In towns and villages, its positive outcomes can be seen in food, fuel wood, and watershed management, contributing to a more resilient food system (FAO, 2011).

Agroforestry systems can be implemented on different farm sizes, ranging from small plots to large tracts of land. On small plots, cereal crops can be combined with nitrogen-fixing trees to enrich the soil. On large tracts of land, trees can be planted in woodlots, along boundaries, and on a landscape scale, where, trees and other vegetation can be cultivated (Sileshi and Mafongoya 2006). For Agroforestry systems to be effective,, they must have positive interactions among their numerous components, leading to final products that are invaluable, and also lessen the likelihood of total harvest failure and reliance on chemical inputs. Properly managed agroforestry plots have demonstrated that trees add value that surpasses any loss in the the crop production process. Nevertheless, these results are not guaranteed; therefore, consideration of the type of agro-forestry system used and the species selected is key (UNEP 2015).

According to Sileshi et al. (2007), if Agroforestry is properly planned and carried out, particularly at the landscape level, enormous benefits will be enhanced, which play a significant role in the sustainability of residents' livelihoods and the ecosystems on which the local community relies for their livelihoods. On the other hand, the environmental and economic services may not be valued by the market, implying that development actors and farmers must bear all the production costs, although the entire nation benefits in the long run. Introducing financial assistance to farmers who practice tree cultivation on their farms can be regarded as a system of payment for environmental services, which will motivate more people to embrace agroforestry.

Cheik (2015) records that progress has been made in integrating the Sustainable Development Goals into the the forest sector. The integration of agroforestry into national sustainable development can help achieve sustainability. Forests and agroforestry, if well-embraced and managed, play a crucial role in achieving the United Nations Millennium Development Goals (MDGs), as well as other globally agreed-upon development goals. Agroforestry has a significant impact on the MDGs, for instance, by eliminating

hunger and poverty while ensuring environmental sustainability. On the other hand,, agroforestry has an indirect role in assisting to meet other MDGs through its social, economic, and environmental services. For instance, agroforestry minimizes child mortality rate and enhances human health through its contribution to food security, providing medicines, as well as a source of income.

In the past, when population was low and agricultural land was abundant, farming practices such as shifting cultivation and bush fallow were able to sustain soil fertility and crop yields (Opoku-Mensah, 2015) by nourishing the soil before cropping. However, the increasing pressure on fertile lands due to population growth and unsustainable farming systems has resulted in a limited availability of fertile lands and soil infertility. The global population is expected to exceed 9 billion by 2050 (Food and Agriculture Organisation (FAO), 2010).

Understanding the respective roles and responsibilities of women and men is crucial for linking knowledge with action to achieve sustainable development. Women and men have different understandings of and knowledge about the natural resources in their environment. Their knowledge base may influence their practices in managing and extracting natural resources, resulting in varied outcomes and impacts. Considering women and men as distinct actors in natural resource management, and taking into account the gendered differences in their social and economic status in communities, is key to promoting sustainability. In her study of rural communities in Malaysia, Hart (2011) observed that women tend to exhibit greater resistance when responding to external pressures compared to men. Agroforestry practices offer practical ways to apply various specialized knowledge and skills in the development of sustainable rural production systems.

Specific objectives

The specific objectives of this study include:

1. Describe the socio-economic characteristics of respondents in the study area.

2. Examine the level of involvement of the respondent in agroforestry in the study area

3. Identify constraints hindering the respondents' involvement in agroforestry in the study area.

Hypothesis of the study

The hypothesis stated in the null form is tested:

Ho: There is no significant relationship between constraints hindering the involvement of the respondents and the respondent's level of involvement in the study area.

Materials and Methods

Akinyele Local Government is located within the town of Ibadan in Oyo State, Southwest Nigeria, and has its headquarters in the Moniya district of Ibadan town. Akinyele LGA is bordered by the Afijio, Lagelu, Ido, and Ibadan North LGAs. Akinvele Local Government Area comprises areas such as Ajibode, Keona, Olugbode, Lgboloyin, Onikarahun, and Motunde. It occupies an area of 464.892 square kilometers with a population density of 516 persons per square kilometer. Using a 3.2% growth rate from 2006 census figures, the estimated population for 2010, according to the local government, is 239,745. It was named after the late Olubadan, Isaac Babalola Akinyele. An elected chairman and 12 councilors govern the local government, one elected from each ward. Interesting landmarks within Akinyele LGA include the Nigerian Institute of Social and Economic Research, the International Institute of Tropical Agriculture, the Federal School of Statistics, and Bowen's tomb. On account of extensive fertile soil, which is suitable for agriculture, the main occupation of the people is farming. There are large hectares of grassland suitable for animal rearing, vast forest reserves, and rivers. People in the area grow a variety of arable crops, including vegetables, maize, yams, and food crops.

Sampling Procedure and Sample Size

A multi-stage sampling procedure was used for this study. Purposely, Akinyele Local Government was selected because it is notable for farming and has the following wards:Ward 1: Ikereku, Ward2:Olanla/Oboda/Labode, Ward3: Arulogun/Eniosa/ Aroro, Ward 4: Olode/Amosun/Onidundu, Ward 5: Ojo-Emo/Moniya, Ward 6: Akinyele/Isabiyilrepodun Ward 7: Iwokoto/Talonta/Idi-oro, Ward 8: Ojoo/Ajibode/Laniba, Ward 9: ljaye/0jedeji, Ward 10: Ajibade/Alabata/Elekuru, Ward 11: Olorisa-oko/Okegbemi/Mele, Ward 12: Iroki. Secondly, random selection settlements/villages where Agroforestry is practiced, including Alabata, Ajibade, Onirere, and Ijaye. Thirdly, the Simple random sampling technique was used to select respondents in the villages of the chosen wards, resulting in a total of 80 questionnaires (the sample size) that were administered for the study.

Analysis of data

The data collected was subjected to descriptive and inferential Statistical analysis using statistical tools such as frequency counts, mean, percentage, and PPMC.

Results and Discussion

Table 1: Socioeconomic Characteristics of the respondents in the study area.

VARIABLE	FREQUENCY	PERCENTAGE
Age		
Below 20	**3**	**3.8**
21-30	**8**	**10.0**
31-40	**20**	**25.0**
41-50	**15**	**18.8**
Above 50	**34**	**42.5**
Marital status		
Single	**7**	**8.8**
Married	**63**	**78.8**
Divorced	**6**	**7.5**
Separated	**4**	**5.0**
Education		
No formal education	**11**	**13.8**
Primary	**6**	**7.5**
Secondary	**34**	**42.5**
Tertiary	**29**	**36.3**
Household size		
Less than 5	**34**	**42.5**
5-10	**29**	**36.3**
Above 10	**17**	**21.3**
Religion		
Christianity	**39**	**48.8**
Islam	**23**	**28.8**
Traditional	**18**	**22.5**
Experience		
Below 5 years	**28**	**35.0**
5-10 years	**31**	**38.8**
11-15 years	**10**	**12.5**
Above 15	**11**	**13.8**
Other occupation		
Rearing animal	**10**	**12.5**
Civil servant	**20**	**25.0**
Trading	**41**	**51.3**
Artisan	**9**	**11.3**
Mode of land acquisition		
Purchase	**28**	**35.0**
Lease/rent	**24**	**30.0**
Gift	**7**	**8.8**
Inheritance	**21**	**26.3**
How often do you sell		
Daily	**33**	**41.3**
Weekly	**17**	**21.3**
Seasonal	**30**	**37.5**

In what form		
Fresh	**58**	**72.5**
Dried	**12**	**15.0**
Processed	**10**	**12.5**
How do extension agents visit you		
Monthly	**7**	**8.8**
Yearly	**27**	**33.8**
Never	**46**	**57.5**
Total	**80**	**100,0**

Field Survey, 2024

Table 1 above reveals the socio-economic characteristics of the respondents, with 42.4 percent falling within the age range of above 50 years. This indicates that most farmers are elderly individuals, which reduces the rate of agroforestry practiced by women. This report is in tandem with Tokede et al. (2020), who state that 50 years ago, people were more engaged in farming activities. The study further reveals 78.8 percent of the respondent are married, this indicates that the respondent are productive and contribute to the feeding of the family i.e. sustenance of the family because married people tend to feed more members of the family and would therefore adopt innovations to ensure that they can meet the needs and this correlate with Mohammed, Achem and *Abdulquadr (2014)* that reported that marriage and adoption of innovation is related. Also, 42.6 percent of the respondents had secondary education, and 36.3 percent had tertiary education, which indicates that the respondents are literate and can understand innovations used in agroforestry practice. Additionally, 42.5 percent of the respondents had a household of less than 5. Furthermore, the results show that 48.8 percent of the respondents are Christians, 28.8 percent are Muslims, and 22.5 percent are traditional worshippers. The study also indicates that 35 percent of the respondents have less than 5 years of experience, while 38.8 percent have 5-10 years of of experience.

The study also shows that 35 percent of the respondentss acquired their land through purchase, and 30 percent obtained their land through lease or rent. Additionally, 72.5 percent of the respondents sell their produce fresh, indicating that a larger population sells their produce fresh due to a a lack of storage and processing facilities.

Table 2: Level of involvement in agroforestry by respondents in the study area.

Level of involvement	Once a year	Twice a year	Regular	Not at all
Taungya	48(60.0)	0(0.0)	0(0.0)	32(40.0)
shifting cultivation	54(67.5)	0(0.0)	0(0.0)	26(32.5)
Improved fallow practice	49(61.3)	0(0.0)	0(0.0)	31(38.8)
planting trees and crops simultaneously	40(50.0)	0(0.0)	0(0.0)	40(50.0)
fuel wood production	51(63.8)	0(0.0)	0(0.0)	29(36.3)
alley cropping	43(53.8)	0(0.0)	0(0.0)	37(46.3)
wind break	61(76.3)	0(0.0)	0(0.0)	19(23.3)
paddock system	33(41.3)	0(0.0)	0(0.0)	47(58.8)

Field Survey, 2024

The Results in Table 2 show the level of involvement of the respondent in the study area. It shows that 60 percent of the respondentss are involved in the taungya system once a year, 67.5 percent of the respondents are involved in shifting cultivation once a year, and 61.3 percent of the respondents are involved in improved fallow once a year. It will help the respondents to produce a large amount of agroforestry produce. The analysis reveals that 50 percent of the respondents are involved in planting trees. The study further reveals that 63.8 percent of the respondents are involved in fuelwood production, which enhances the rate of tree felling and conversion to fuel production, and will also serve as a a source of energy. 53.8 percent of the respondents are involved in alley cropping. 76.3 percent of the respondentss are involved in practicing windbreak, which shows that a higher percentage of respondents are involved in windbreak, helping to reduce the effect on young plants and preventing building structures from collapsing or falling off.

Table 3: Constraints hindering Respondents' involvement in Agroforestry in the study area.

Constraints	**Severe**	**Mild**	**Not a constraint**
Land acquisition	16(20.0)	34(42.5)	30(37.5)
Distance of the extension staff office to the farm	23(28.8)	38(47.5)	19(23.8)
Insufficient labor	19(23.8)	38(47.5)	23(28.8)
Inadequate motivation from family members	31(38.8)	22(27.5)	27(33.8)
Absence of strong co-operative society	25(31.3)	33(41.3)	22(27.5)
Lack of finance(capital and credit)	10(12.5)	48(60.0)	22(27.5)
Religious influence	19(23.8)	15(18.8)	46(57.5)
Preservation/storage/processing facilities	17(21.3)	63(78.8)	0(0.0)
Culture	13(16.3)	17(21.3)	50(62.5)
Disease/pest infestation	11(13.8)	58(72.5)	11(13.8)
Lack of technical know-how	24(30.0.)	35(43.8)	21(26.3)
Encouragement from society	11(13.8)	40(50.0)	29(36.3)
Water shortage during dry season	13(16.3)	35(43.8)	32(40.0)

Field Survey, 2024

Result of analysis in Table 3 shows the constraints faced by the respondents in the study area in the practicing of agro forestry. It shows that 42.5 percent of the respondent chose that land acquisition was mild a constraint, 47.5percent of the respondent chose that insufficient labor was a mild constraint , Also, 38.8 percent of the respondent chose that inadequate motivation was a severe constraint, this shows that inadequate motivation have a very high percentage which will reduce the rate of involvement and agro forestry produce. The study also shows that 60.0 percent of the respondent chose that lack of finance was a mild constraint. Furthermore, the study also shows that 23.8 percent of the respondent chose that religion was a severe constraint, which describes that religion is not a constraint in practicing agro forestry, while Result shows that 43.8 percent of the respondent chose that water shortage was a mild constraint in the study area.

Table 4: PPMC Analysis on the relationship between the constraints hindering respondent practice in agro forestry and the respondents involvement level.

Variable	R-value	P- value	Decision
Constraints and involvement level	0.387	0.00	S

S-significant (≤ 0.05)

N.S-Not significant (> 0.05)

The result of analysis above shows that the relationship between the constraints hindering respondents practice and the respondent level of involvement, with the r-value and p-value of the relationship. It revealed that the constraints hindering respondent practice is significant to the respondent involvement level which means the women farmer's level of involvement is determined by the constraints encountered in the study area.

Conclusion and Recommendations

Based on the outcome of the findings on the socio economic characteristics of the respondents, it was observed that agro forestry practice in the study area is dominated by age 50 and above farmers, they are married, experienced adult with good educational background I which most of them are traders. The study also reveals that most of the farmers are Christians and they acquire their land by purchase and often sell their produce daily and in fresh form. The study further shows different level of involvement of the farmers,which shows that most of the respondents practice all the type of agro forestry but once a year was the most occurring rate at which they involve in it which will sometimes help to reduce the stress due to the larger percentage of the aged respondent which will also increase agro forestry produce. Also, the study also shows that the constraints such as land acquisition, distance of extension, insufficient labor, lack of finance culture, lack of technical knowhow, water shortage and encouragement most of the constraints are mostly not a constraint or a mild constraint to the farmers because these constraints determines the level of involvement. It is therefore recommended that Government and Non-Government agency should create more Awareness and encouragement of young women farmers to get involved in agroforestry for better productivity.

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SUBTHEME 8: WILDLIFE MANAGEMENT AND BLUE ECONOMY IN THE ERA OF CLIMATE CHANGE

CAUSES OF MORTALITY IN GRASSCUTTERS (*THRYONOMIS SWINDERIANUS* TEMMINCK) REARED IN CAPTIVITY

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Abstract

The survival rate of grasscutters in captivity is the primary limiting factor for the domestication and conservation of the animal. Therefore, this study aims to investigate the causes of mortality in captive grasscutters. Two hundred and thirty-six grasscutters were investigated in captivity to identify the standard features and ailment responsible for mortality. The study spanned ten years (2015-2024). The highest mortality percentage (55.56%) was recorded in 2017, while the lowest (10.71% was recorded in 2021. Causes of mortality in the unit include: pneumonia, traumatic injuries, cannibalism, respiratory tract infection, bloat, paralysis of the neck, neck swelling, worm infestation, and forced weaning. Pneumonia ranked highest among the causes of mortality in the unit, followed by mortality as a result of traumatic injuries, and lastly, mortality through forced weaning (0.81%). However, some grasscutters died of unidentified causes. Given conducive weather conditions and good management practices, grasscutters reared in captivity can serve as a reliable source of animal protein and a source of income.

Keywords: Grasscutters, Captivity, Mortality, Pneumonia, Traumatic Injuries

Introduction

Climate (*klima*, an ancient Greek word meaning *"inclination") is commonly defined* as the long-term average of weather, typically averaged over 30 years (Planton, 2013; Glossary of Meteorology, 2008). Over the years, climate change, whether natural or caused by human activities, has gradually become a global crisis. The fact that climate change has affected man and biodiversity tremendously is an understatement. Unless greenhouse gas emissions are severely reduced, climate change could cause the extinction of a quarter of land animals, birds, and plants. To curb the extinction of animals like the grasscutters, domestication in captivity is encouraged and practiced. With captive rearing, human-induced climate change, which could lead to losses in biological diversity and the goods and services that ecosystems provide to society, will be minimized to the barest minimum (IPCC 2001).

Grasscutters (*Thryonomys swinderianus) are referred to as mini-livestock, which have been used for centuries in the tropics through gathering, hunting,* and sometimes poaching (Hardouin, 1995). They are also referred to as bush meat – a general term for the flesh of forest mammals (Fa *et al.,* 2003). As noted by (Inamdar *et al*. 1999), bush meat has become an essential source of protein for rural households and a significant source of revenue, which has few rivals in terms of trade, because it is accessible, highly transportable, has a high value: weight ratio, is preserved at low cost and has good storage qualities when smoked. Recently, these animals have been widely bred and eaten. Oke *et al*. (2004) clearly stated that Nigerians consume only about a quarter of the minimum daily animal protein requirement. The domestication of the grasscutter

is being encouraged in West Africa to help address the problems of high demand for its meat, reduce aggressive hunting with complete regard for conservation of the species and the environment. Akegbejo-Samsons (1996) assert that the active manipulation of grasscutters' habitats for the benefit of humanity will negate the imminent extinction of these animals from the wild, either through bush burning and urbanization.

Additionally, their preservation, protection, and restoration necessitate public interest in effective management, which will curb hunger, provide employment, and consequently reduce poverty not only in Nigeria but also across Africa as a whole (Wikipedia, 2001). Grasscutters exhibit a high degree of docility and prolificacy in captive rearing, but a high mortality rate could be a significant threat to the commercial production of the animals. There is a paucity of literature on the health problems of the grasscutter. The objective of this paper is to investigate the potential causes of mortality in grasscutter due to losses in captive rearing and to offer possible solutions.

Materials and Methods

Study Area and Animal Management

The study was conducted at the Grasscutter Research and Domestication Unit of Forestry Research Institute of Nigeria (FRIN). Two hundred and thirty-six grasscutters were housed in concrete floor hutches. Each hutch is composed of two compartments with a hole in between, allowing for easy access to the animals. The hutch doors are positioned at the top of the compartments. The building is lined with wire mesh and covered with cellophane nylon, which helps regulate the ambient temperature. The animals were served forage (*Pennisetum purpureum*) once daily ad libitum between 0800 hours and 1000 hours, and concentrate supplements mixed with multivitamins and a small amount of water added (to reduce dustiness and prevent respiratory tract infections) at 1400 hours. A routine check of the animals was done every morning before the cages were cleaned of remnants from the previous day and fresh ones were served. Mineral lick was served continually. Tables 1 and 2 show the proximate compositions of the forages and concentrates served, respectively.

Table 1. Proximate Composition of Elephant Grass (*P. purpureum*)

Parameter	Percentage composition (%)
Moisture	15.65
Crude protein	7.38
Crude fibre	29.65
Ether extract	0.42
Ash	6.45
Nitrogen-free extract	40.75

Table 2. Proximate Composition of Concentrate Supplement

Ingredient	Percentage composition (%)
Crude protein	14.76
Crude fibre	7.01
Ether extract	4.40
Metabolizable energy (kcal/g)	2422.98
Energy: protein	164:16

Statistical Analysis

The data were analyzed using descriptive statistics in the Statistical Package for the Social Sciences (SPSS) software, and the results were presented in the form of tables.

Results and Discussion

Table 3 presents the mortality report recorded during the study period from 2015 to 2024. The results in Table 3 show that 2017 had the highest percentage of mortality (55.56%), followed by 32.50% animal losses recorded in 2022 and 30.67% lost in 2015, respectively. While only 10.71% of animals died in 2021, both 2016 and 2018 saw a 17.18% loss of grasscutters. The lowest figure for animal mortality recorded in 2021 could be attributed to good management practices, as noted by previous authors in related studies (Inamdar *et al*., 1999; Alarape and Ayodele, 2003).

The percentage mortality rate as related to causes is represented in Table 4. In 2019, 0.81% was recorded for mortality due to forced weaning. It was as a result of the death of the nursing doe, and there was no foster mother to nurse the young in the unit. Probably, the views of Cowie (1990) that highest post weaning survival rate is obtained from grasscutters weaned at six weeks to enable them obtain the full benefit of lactation (adequate nutrition and protection against infection by way of maternal antibodies), thus enhancing their post-weaning survival in captivity supports the result got from the study. There were also records of unknown factors leading to the death of grasscutters in the unit. This fall, in tandem with the views of Ademosun (1987) and Danilevsky (1991), it is acknowledged that animals in captive rearing are sometimes subjected to stressful factors, including physical discomfort, behavioral deprivation, environmental reactions, humidity, and high and low ambient temperatures.

Pneumonia was reported as the highest cause of mortality, followed by mortality as a result of traumatic injuries. Traumatic injuries could be caused by aggression, competition, restlessness, stress, agonistic behaviour, among others. Honess and Marin (2006) stated that captive animals may exhibit abnormal levels of social aggression and self-harm related to aspects of the physical and social environment, which depend on the species and individual factors such as gender, age, and background (e.g., being raised in the wild or captivity). Aggression is a behaviour that is intended to increase the social dominance position of other organisms (Ferguson and Beaver, 2009). Also, agonistic behaviour is a form of aggression that threatens and intimidates, but without any physical harm, as opined by Van Staaden *et al*. (2011). It includes the display of body size, claws and teeth, facial expressions, vocalizations such as bird song, the release of chemicals, and changes in coloration. These could frighten others, causing them to scamper for safety and thereby inflict injuries on themselves.

Table 3. Mortality record of grasscutters in the unit from 2015 to 2024

Year	Total no of animals	Mortality	Percentage Mortality
2015	75	23	30.67
2016	72	11	15.28
2017	54	30	55.56
2018	64	11	17.18
2019	79	20	25.31
2020	78	21	26.92
2021	84	9	10.71
2022	80	26	32.50
2023	58	12	20.69
2024	45	14	31.11

Table 4. Causes of mortality in grasscutters in the unit from 2015 to 2024

Year	The highest cause of mortality	% mortality	The lowest cause of mortality	% mortality
2015	Unidentified	10.30	Paralysis of the neck	1.72
2016	Pnuemonia	20.00	Neck swelling	2.23
2017	Traumatic injuries	9.40	Unidentified	3.07
2018	Traumatic injuries	15.20	Worm infestation	1.27
2019	Cannibalism	10.60	Forced weaning	0.81
2020	Traumatic injuries	31.10	Unidentified	2.59
2021	Pnuemonia	4.60	Bloat	0.92
2022	Respiratory tract infection	4.70	Traumatic injuries	3.57
2023	Pnuemonia	18.70	Traumatic injuries	2.50
2024	Pnuemonia	8.40	Traumatic injuries	2.78

Conclusion

The overall findings of this study showed that though the grasscutters are still undergoing domestication, they exhibit relatively healthy characteristics. Given the low mortality rate obtained from the study, good management practices such as adequate feeding, close observation, early detection of signs and symptoms of ill health, and routine examination are hereby recommended for successful breeding.

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GENETIC RESOURCE IN CONSERVATION OF WILDLIFE SPECIES

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Abstract

Molecular genetics is an aspect of biology that focuses on the structure, function, and regulation of genes at the molecular level. It involves the study of DNA, RNA, and proteins to understand how genetic information is stored, transmitted, and expressed within organisms. Molecular genetics plays a vital role in wildlife conservation by providing insights into genetic diversity, population dynamics, adaptive potential, and evolutionary dynamics. Genetic tools, such as DNA barcoding, microsatellite analysis, and whole-genome sequencing, help enhance species identification, monitor genetic health, and inform conservation strategies. However, in Nigeria, the application of molecular genetics in wildlife conservation is limited due to challenges such as inadequate funding, limited laboratory infrastructure, and a shortage of skilled personnel, which hinder its application. This review aims to highlight the need for the adoption of molecular genetics in wildlife conservation, assess the success recorded so far, and identify the applications, benefits, and challenges of molecular genetics in Nigerian wildlife conservation. Strengthening research capacity, enhancing policy frameworks, and promoting international collaboration are crucial for integrating molecular genetics into Nigeria's conservation efforts.

Keywords*: Genetic Diversity, Gene bank, Conservation Challenges, wildlife, Nigeria*

Introduction

Its genetic composition fundamentally determines the biological characteristics of an organism. Genes, the fundamental units of heredity, can be broadly classified into two categories: structural and regulatory. Structural genes encode proteins that serve as enzymes facilitating biochemical reactions or as essential components of cellular structures. In contrast, regulatory genes control the expression of structural genes, determining the rate and timing of protein synthesis in response to internal and external signals. The understanding of these genetic principles has been significantly advanced through extensive molecular research (Alberts *et al.,* 2015; Griffiths *et al.,* 2020).

The foundation of modern genetics was laid by Watson and Crick's discovery of the DNA double-helix structure in the 1950s, which provided crucial insights into genetic replication and expression (Watson and Crick, 1953). Since then, extensive research has deepened the understanding of how genetic information is translated into cellular and organismal traits. Evolutionary adaptations arise through alterations in DNA sequences, enabling species to respond to environmental changes over generations (Futuyma and Kirkpatrick, 2017; Ridley, 2004). These principles form the basis of molecular genetics, which has become an indispensable tool in various scientific disciplines, including conservation biology.

In Nigeria, wildlife conservation is increasingly incorporating molecular genetics and biotechnology to address pressing challenges such as habitat loss, poaching, and declining genetic diversity. The application of molecular tools facilitates species identification, population monitoring, and genetic rescue initiatives, all of which are critical for effective conservation strategies (Frankham *et al.,* 2017; Ogugua *et al.,* 2021). By utilizing techniques such as DNA barcoding, whole-genome sequencing,

microsatellite analysis, and environmental DNA (eDNA) analysis, conservationists can assess genetic variability, detect cryptic species, and identify genetic bottlenecks that may threaten population viability (Hoffmann and Sgro, 2011). Besides, molecular genetics plays a vital role in wildlife forensics, supporting the detection and protection of illegal wildlife trade, which remains a significant conservation concern in Nigeria (Ogugua *et al.,* 2011).

Despite its potential, the application of molecular genetics in wildlife conservation in Nigeria faces considerable challenges. These include inadequate funding, insufficient infrastructure, and a shortage of skilled personnel (Ogunbiyi *et al.,* 2022). Furthermore, the integration of genetic tools into conservation policies and wildlife management programs remains limited. Responding to these challenges requires increased investment in molecular research, capacity-building initiatives for conservation scientists, and enhanced collaboration between government agencies, research institutions, and international conservation organizations. By strengthening these areas, Nigeria can maximize the benefits of molecular genetics in biodiversity conservation and contribute to global efforts in wildlife protection.

1. Nuclear Markers in Wildlife Conservation

Nuclear DNA markers play a crucial role in DNA Fingerprinting and wildlife Conservation, enabling the assessment of genetic diversity, population structure, and species identification. The most commonly employed nuclear markers are random amplified polymorphic DNA (RAPD), amplified fragment length polymorphism (AFLP), and Microsatellites or short sequence repeats (SSR) (Liu and Cordes, 2004; Schlotterer, 2004). RAPD and AFLP markers are handy for genetic diversity studies due to their ability to screen a large number of loci concurrently. However, their differentiating power follows a specific hierarchy: SSR > AFLP > RAPD, with SSRs providing the highest level of resolution (Powell *et al.,* 1996; Manel *et al.,* 2002). Both RAPD and AFLP are considered dominant markers as they detect the presence or absence of bands without distinguishing between homozygous genotypes. In contrast, SSRs are co-dominant markers, allowing for the identification of both alleles at a given locus, thereby providing more accurate differentiation between homozygotes and heterozygotes (Guichoux *et al.,* 2011). AFLP markers offer an advantage in that they do not require prior molecular sequence information, making them particularly useful for non-model organisms. However, SSR markers necessitate prior sequence knowledge to design species-specific primers, which can be a limitation in specific applications (Vos *et al.,* 1995; Sunnucks, 2000). These markers have been widely used for wildlife genetic studies, with their applications summarized in Table 1, showcasing their significance in forensic identification, population genetics, and conservation management.

1.1. Microsatellites (Simple Sequence Repeats, SSRs)

Simple sequence repeats (SSRs) markers, also known as microsatellites, are highly polymorphic DNA markers consisting of short nucleotide motifs (1-5 base pairs) repeated in tandem up to 100 times (Tautz, 1989). These markers are abundant, widely distributed across eukaryotic genomes, and co-dominant, meaning that heterozygotes can be distinguished from homozygotes due to variations in the number of repeat units (Jarne and Lagoda, 1996). Length polymorphisms can be easily detected on high-resolution gels (e.g., Sequencing gels). It is suggested that the variation or polymorphism of SSRs is a result of polymerase slippage during DNA replication or unequal crossing-over (Levinson and Gutman, 1987). SSRs are not only very common but also highly variable for the the number of repetitive DNA motifs in the genomes of eukaryotes (Vosman and Arens, 1997; Rallo *et al.,* 2000; van der Schoot *et al.,* 2000).

Microsatellites have several advantages in wildlife conservation. High polymorphism levels make them ideal for population genetics, kinship analysis, and conservation studies (Schlotterer, 2004). It enhances co-dominant inheritance and allows for an accurate assessment of genetic diversity and differentiation among populations (Selkoe and Toonen, 2006). Amplifiable via PCR, making them a valuable tool even for degraded DNA samples in conservation genetics (Palsboll *et al.,* 1997). SSRs have an advantage over other molecular markers. For example, microsatellites allow the identification of many alleles at a single locus. They are evenly distributed throughout the genome, offering more detailed population genetic insights than bi-parental inheritance. They are co-dominant, highly polymorphic, and specific (Jones et al., 1997), requiring little DNA. Many challenges affecting the adoption of the SSRs and microsatellite loci have not been identified in many species due to the complexity of isolation and genotyping (Guichoux *et al.,* 2011). Mutation rates in flanking regions limit the design of cross-specific primers (Ellegren, 2004), and high mutation rates can lead to homoplasy, complicating phylogenetic and population structure analyses (Estoup *et al.,* 2002).

SSRs have been adopted for many studies, for example, Arif *et al.* (2010) analyzed seven microsatellite loci to assess molecular diversity in captive-bred and reintroduced populations of Arabian oryx (Oryx leucoryx), Ryberg *et al.,* (2002) used microsatellite markers to investigate genetic variation among coastal and inland alligator (*Alligator mississipiensis*) populations in Texas, revealing patterns of gene flow. Lougheed *et al.* (2000) compared microsatellites and RAPD markers to analyze genetic differentiation in massasauga rattlesnake (*Sistrurus catenatus*) populations, confirming the reliability of microsatellites in defining conservation units.

1.2. Single-nucleotide polymorphism (SNP)

SNPs are the most common molecular marker analysis as they show abundant polymorphism in any genome. SNP involves both coding and non-coding regions and reveals hidden polymorphism which other markers cannot easily detect. SNPs can detect polymorphisms induced by point mutations, which give rise to diverse alleles comprising alternative bases at a given nucleotide position within a locus (Aitken *et al.,* 2004). A single-nucleotide variant (SNV) is a standard definition for a single-nucleotide change in DNA sequence. SNP within a locus can replace the four bases (Adenine A, Thymine T, Cytosine C, and Guanine G) in a particular stretch of DNA at the SNP site. However, most of the SNPs are restricted to only one of two alleles (either C/T or A/G) and have been observed as bi-allelic. SNP markers are inherited as codominant markers. SSCP analysis has been commonly used for SNP identification, heteroduplex analysis, and direct DNA sequencing. Some SNPs do not affect cellular function and therefore reveal no effect, but others have been associated with diseases such as cancer and influence physiological responses to drugs (Liu, 2027).

1.3 Random Amplified Polymorphic DNA (RAPD)

RAPD was the first PCR-based molecular marker technique developed, and it is widely used in conservation genetics due to its simplicity, cost-effectiveness, and ability to generate polymorphic markers without prior genomic knowledge (Williams *et al.,* 1990). RAPD employs short, arbitrary primers under low-stringency PCR conditions to amplify multiple loci, allowing for the rapid assessment of genetic variation (Hadrys *et al.,* 1992). RAPD markers are easily developed, and because they are based on PCR amplification followed by agarose gel electrophoresis, they are quickly and readily detected. The RAPD technique was used extensively to study genetic diversity, population structure, and genetic monitoring. For example, it was used to assess genetic variation in Far-Eastern leopards *(Panthera pardus orientalis)*, showing lower genetic diversity in captive populations (Chelomina *et al.,* 1999). Similarly, wild

populations of mouse lemurs (*Microcebus murinus*) displayed higher diversity compared to captive groups (Neveu *et al.,* 1998). Despite its advantages, RAPD has limitations, including low reproducibility, the dominance of markers (inability to distinguish heterozygotes), and sensitivity to PCR conditions, which lead to high genotyping error rates (Ellsworth *et al.,* 1993). However, it remains a valuable tool for evaluating genetic diversity, population structure, and conservation planning for various endangered species.

1.4.Amplified Fragment Length Polymorphisms (AFLP)

Amplified fragment length polymorphisms (AFLP) based genomic DNA fingerprinting is a technique used to detect DNA polymorphism. AFLP is a polymerase chain reaction (PCR)-based technique (Vos et al., 1995) that has been reliably used for determining genetic diversity and phylogenetic relationships between closely related genotypes. AFLP analysis combines both the reliability of restriction fragment length polymorphism (RFLP) and the convenience of PCR-based fingerprinting methods. AFLP markers are generally dominant and do not require prior knowledge of the genomic composition. AFLPs are produced in significant numbers and are reproducible.

AFLP disadvantages include that alleles are not easily recognized, have medium reproducibility, are labour-intensive, and have high operational and Development costs (Karp *et al.,* 1997). Furthermore, AFLP requires knowledge of the genomic sequence to design primers with specific selective bases. Dominant markers, such as RFLP and RAPD, are limited in their ability to determine parentage precisely. They can readily be used to establish that two individuals are not the same, but the statement that two individuals are identical is usually only approximate, and no formal statistics can be attached to this assertion. The advantages of this technique includes; no need for prior knowledge of any sequence information, multiple bands are produced per each experiment, these bands are produced from over the genome, the technique is reproducible, and the data can be stored in the database in database lie AmpliBASE MT (Majeed *et al.,* 2004) for comparison purposes.

Table 1. Application of Nuclear Markers in Wildlife Conservation

No. of Samples	No. of Populations	Taxa	Study Focus	Marker	Authority
52	4	African elephant (*Loxodonta africana*)	Genetic structure and poaching forensics	Microsatellites (SSR)	Wasser et al. (2004)
86	3	Bengal tiger (*Panthera tigris tigris*)	Individual identification and population genetics	Microsatellites (SSR)	Mondol et al. (2009)
110	6	Brown bear (*Ursus arctos*)	Population differentiation	AFLP and Microsatellites	Paetkau et al. (1995)
74	2	Grey wolf (*Canis lupus*)	Genetic diversity and hybrid detection	SNPs and Microsatellites	Pilot et al. (2010)
125	5	Snow leopard (*Panthera uncia*)	Non-invasive DNA monitoring	Microsatellites (SSR)	Janecka et al. (2008)

No. of Samples	No. of Populations	Taxa	Study Focus	Marker	Authority
98	8	Wild boar (*Sus scrofa*)	Genetic Structure and conservation	RAPD, AFLP	Vernesi et al. (2003)
67	4	Red fox (*Vulpes vulpes*)	Parentage and population structure	Microsatellites (SSR)	Baker et al. (2004)
105	7	Indian rhino (*Rhinoceros unicornis*)	Genetic Variability and conservation	Microsatellites (SSR)	Dutta et al. (2017)
89	3	European otter (*Lutra lutra*)	Population connectivity and inbreeding	SNPs	Muñoz-Fuentes et al. (2009)
122	6	African lion (*Panthera leo*)	Population genetics and hybrid detection	Microsatellites (SSR)	Antunes et al. (2008)

2 Mitochondrial DNA in Conservation Genetics

Mitochondrial DNA (mtDNA) has been extensively utilized in conservation genetics due to its unique properties, including maternal inheritance, lack of recombination, and a relatively high mutation rate compared to nuclear DNA (Ayise, 2000; Moritz, 1994). The mitochondrial genome is a circular DNA molecule that typically contains 36-37 genes, including two ribosomal RNA (rRNA) genes, 22 transfer RNA (tRNA) genes, and 12 or 13 protein-coding genes that encode subunits of oxidative phosphorylation complexes (Boore, 1999). Furthermore, in these coding sequences, the control region (CR), also known as the displacement loop (D-loop), plays a crucial role in mtDNA replication and transcription regulation (Saccone *et al.,* 2000). Unlike nuclear DNA, mitochondrial DNA (mtDNA) lacks histones and introns, resulting in a compact genome with minimal non-coding regions (Wallace, 2007). Due to its limited DNA repair mechanisms, mtDNA accumulates mutations at a rate 5-10 times higher than nuclear DNA, making it a valuable molecular marker for studying evolutionary processes (Brown *et al.,* 1979; Pesole *et al.,* 1999). However, mutation rates vary across different regions of the mitochondrial genome, allowing for the use of specific markers depending on the level of taxonomic resolution required (Galtier *et al.,* 2009). The widespread application of mtDNA in conservation genetics has been facilitated by the Development of universal primers, enabling the amplification of conserved mitochondrial regions across diverse taxa (Kocher *et al.,* 1989). Each cell contains multiple copies of mtDNA, and it is often possible to extract and amplify mtDNA sequences from highly degraded samples, making it especially useful in forensic investigations and ancient DNA studies (Paabo *et al.,* 2004).

2.1. Ribosomal DNA (12S and 16S rDNA)

Mitochondrial ribosomal DNA (rDNA), specifically 12S and 16S rRNA genes, serves as a crucial marker in phylogenetic and conservation genetics. The 12S rDNA is highly conserved and is often applied to infer phylogenetic relationships at higher taxonomic levels, such as phyla or subphyla (Janczewski *et al.,* 1995). Conversely, 16S rDNA is typically used for phylogenetic studies at mid-taxonomic levels such as families or genera, making it a valuable tool for assessing moderate to long divergence times (Wang *et al.,* 2003). Ribosomal DNA (rDNA) is used for forensic identification, genetic diversity studies, endangered species conservation, and gaining phylogenetic insights. Many studies have adopted

12S and 16S rDNA for wildlife forensics, aiding species identification and conservation efforts (Prakash *et al.,* 2000; Gurdeep *et al.,* 2004). Studies include molecular analysis of elopomorph fishes using 12S rRNA sequences, which successfully distinguished the monophyletic Elopomorpha from Clupeomorpha, supporting taxonomic clarity (Wang *et al.,* 2003). Skate species in the Mediterranean and Black Seas were classified using Mitochondrial 16S rDNA, refining their systematic relationships (Turan, 2008).

2.2 Mitochondrial Protein-Coding Genes

Mitochondrial protein-coding genes evolved at a significantly faster rate, making them powerful markers for inferring evolutionary history at lower taxonomic levels, such as families, genera, and species. Their mutation rate provides greater resolution in distinguishing closely related species, which is essential for taxonomic classification and resolving uncertainties in conservation genetics. The cytochrome b gene analysis has been instrumental in assessing genetic diversity in Tibetan gazelle (*Procapra picticaudata),* providing insights for conservation strategies (Zhang and Jiang, 2006). Another study that employed cytochrome b sequences has also been used to investigate the genetic divergence between Korean and Chinese gorals, revealing substantial genetic variation and emphasizing the importance of molecular data for conservation planning (Min *et al.,* 2004). Cytochrome b and Chroo-Helicase-DNA-binding (CHD) genes have been utilized to determine whether seized animal specimens originated from illegally hunted wildlife (An *et al.,* 2007). Johnson and O'Brien (1997) combined NADH dehydrogenase subunit 5 and 16S rRNA gene sequences for phylogenetic analysis of 35 felid species, successfully identifying eight monophyletic evolutionary lineages within the Felidae family.

2.3.Non-Coding or Control Region Sequences

The Non-coding, also known as the control region (CR), is composed of three domains, including the ETAS (extended termination associated sequences) domain, the Central domain, and the CSB (Conserved sequence block) domain. Each of the three domains presents a distinct pattern of variation; both the ETAS and CSB domains evolve rapidly, whereas the central domain remains taxonomically conservative. Iyengar et al. (2006) compared the CR sequences from several captive animals with those of the Oryx species, and the subsequent phylogenetic analysis of sequence variations revealed a close grouping of *Oryx leucoryx* with *Oryx gazelle* rather than Oryx dammah. Recently, Khan et al. (in press) observed typical sequence variation in the CR gene of 23 captive-bred and reintroduced Oryx leucoryx samples, in the form of 7 haplotypes. One of these haplotypes has been reported earlier, while the remaining 6 haplotypes are novel and represent different lineages from the founders. The CR sequences have been used to investigate the genetic status and evolutionary history of the Tibetan gazelle (Zhang and Jiang, 2006).

Table 2. Application of Mitochondrial DNA Marker in Wildlife Conservation

No. of Samples	No. of Populations	Taxa	Study Focus	Marker	Authority
95	17 Locations	African sable (*Hippotragus niger*)	Genetic structure	Cyt b, CR	Pitra et al. (2002)
47	3	Black muntjac (*Muntiacus crinifrons*)	Population structure	CR	Wu et al. (2006)

No. of Samples	No. of Populations	Taxa	Study Focus	Marker	Authority
40	1	Chinese water deer (*Hydropotes inermis*)	Genetic diversity	CR	Hu et al. (2006)
73	1	Houbara bustard (*Chlamydotis undulata*)	Genetic diversity	CR	Idaghdour et al. (2004)
18+	2 Locations	Rock-wallaby (*Petrogale sp.*)	Population structure	CR	Eldridge et al. (2001)
182	14 Zoos (Different Countries)	Scimitar-horned oryx (*Oryx dammah*)	Genetic diversity	CR	Iyengar et al. (2007)
19+	5 Locations	Beisa oryx (*Oryx beisa*)	Genetic diversity	CR, Cyt b	Masembe et al. (2006)
21+	2 Locations	Arabian oryx (*Oryx leucoryx*)	Genetic diversity	CR	Khan et al. (In Press)
17+	Captive and Field	Indian leopard (*Panthera pardus fusca*)	Species identification	12S rRNA	Pandey et al. (2007)

Challenges Hindering the Adoption of Genetics for Conservation in Nigeria

The adoption of genetic tools for Conservation in Nigeria faces several challenges, including scientific, infrastructural, financial, and policy-related barriers. The lack of well-equipped laboratories for molecular genetics research is a significant constraint. Advanced techniques such as next-generation sequencing (NGS) and genomic editing require sophisticated facilities, which are scarce in Nigeria (Adeola *et al.,* 2021). Furthermore, there is a shortage of trained personnel skilled in molecular biology, bioinformatics, and conservation genomics, which further limits research capacity (Oladipo and Abubakar, 2020). Inadequate funding and high cost of genetic studies, conducting genetic research requires substantial financial investment in laboratory equipment, reagents, and sequencing services. In Nigeria, most funding for conservation research comes from international organizations, with minimal government support (Eze *et al.,* 2019). The high cost of sequencing and limited funding hinder large-scale genetic studies on endangered species. Lack of genetic data and reference genomes has hindered genetic research in Nigeria, as it suffers from a scarcity of baseline genetic data for many native species. Without reference genomes or documented genetic markers, it is challenging to study population genetics and assess genetic health (Umeh *et al.,* 2022). Nigeria lacks specific policies mandating the integration of genetic tools into conservation strategies. Inadequate legal frameworks and weak enforcement of wildlife protection laws allow illegal poaching and habitat destruction to persist (Ajibade *et al.,* 2023). Genetic monitoring is rarely considered in national conservation plans, resulting in its limited application in wildlife management. Genetic sampling requires ethical approval and permits, which can be challenging to obtain in Nigeria.

Furthermore, some local communities hold traditional beliefs that oppose genetic research, viewing DNA collection as intrusive or unnecessary (Bello *et al.,* 2021). International collaboration plays a crucial role in conservation genetics; however, Nigerian researchers frequently face barriers in accessing global genetic databases. Bureaucratic restrictions on

exporting genetic samples further limit opportunities for collaborative research (Okon *et al.,* 2020).

Conclusion

The application of molecular genetics to the management of biodiversity and its habitats will enable one to differentiate genetically differentiated populations, understand inbred populations, and detect loss of genetic diversity, as well as identify hybridization, define sites for reintroduction, and facilitate forensics. With no iota of doubt, the application of molecular genetics will enhance biodiversity conservation efforts.

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ASSESSING THE ANTIOXIDANT PROPERTIES OF CITRUS PARADISI IN CARBON TETRACHLORIDE-INDUCED HEPATOTOXIC DAMAGE IN WISTAR RATS

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Abstract:

This project aimed to evaluate the effect of carbon tetrachloride induced hepatotoxicity i.e., liver damage on the status of antioxidants enzymes and metabolites in rat liver and the possible antioxidant ameliorative effect of Citrus paradisi on various biomarkers of oxidative stress. Animals were weighed and divided into six groups, consisting of five rats per group with different treatments. Treatment with a graded dose of Citrus paradisi (125mg-500mg/kg body weight) caused a significant reduction in serum malondialdehyde in a dose-dependent manner (Group IV-VI). In the same reaction, aqueous seed extract of Citrus paradisi (250mg-500mg/kg body weight) significantly reduces the liver malondialdehyde level (Group IV-VI) but not dose-dependently. Oral graded dose of Citrus paradisi (125p- 500mg/kg body weight). (Group IV-VI) also significantly elevates reduced serum glutathione dose-dependently. The results of the liver's reduced glutathione also followed the same trend as those of the serum. It was concluded that aqueous seed extract of Citrus paradisi has an antioxidant activity with potential free radical scavenging attributes. Therefore, Citrus paradisi can be recommended for the prevention of liver damage caused by carbon tetrachloride toxins.

Keywords: Antioxidant, Carbon tetrachloride, Hepatotoxicity, Hypersensitivity, Metabolism, Oxidative stress.

1. Introduction

Various environmental toxicants and clinically useful drugs can cause severe organ toxicities through the metabolic activation to highly reactive free radicals, including the superoxide and reactive oxygen species (ROS). Aside from reactive oxygen species, certain compounds can also be metabolized to form reactive nitrogen species (RNS). One of the most extensively studied of the environmental toxicants is carbon tetrachloride (CCl_4).

Carbon tetrachloride, which is a tetramethyl methane, has all the hydrogen atoms in methane substituted by chlorine, a member of the halogen series. It is therefore a haloalkane. Because it has no C-H bond, Carbon tetrachloride does not readily undergo free radical reaction. This compound is known to undergo reductive metabolism by cytochrome P450 2E1 (CYP2E1) into a highly reactive trichloromethyl radical (CCl3) and phosgene, which initiates lipid peroxidation, disrupts membrane integrity, and causes cell death (Basu, 2003). There is evidence that various enzymatic and non-enzymatic systems have been developed by the cell to ameliorate the effects of oxidative stress associated with high levels of reactive oxygen species that may result from an imbalance between the oxidant and antioxidant status of any organism.

Citrus paradisi**,** popularly known as grapefruit, is widely cultivated in most countries of the world. Its tree grows up to 3-5 meters high, and its fruit is big, globular, with a nipple at its apex, and bright yellow or lemon-colored (Adeneye, 2008). Its juice is mildly acidic and has a slight bitter taste. In humans, grapefruit seed extract has been reported to possess antibacterial, antifungal, wound-healing, and antioxidant properties (Monsef-Esfahani et al., 2006). Clinical studies have also documented the effectiveness of grapefruit seeds in treating genitourinary tract infections caused by pathogenic organisms such as Pseudomonas

aeruginosa, Klebsiella spp., Staphylococcus aureus, and Escherichia coli (Adeneye, 2008). In Nigerian folkloric medicine, an ethanolic decoction prepared from this seed is employed in the treatment of throat, chest, and genital infections; diarrheal diseases; stomach ulcers; poisonings; diabetes mellitus; obesity; blood deficiency; and as an immunostimulant (Adeneye, 2008).

Certain phytochemicals with potent antioxidant capabilities have been isolated from *Citrus paradisi*. One of these is a bioflavonoid known as aringenin (Lee et al., 2002). Aringenin is the aglycone of the natural glycoside, which constitutes its bitter principle. This principle is believed to act in concert with other phytochemicals to exert antioxidant properties.
Herbal treatment is an essential component of traditional medicine practiced worldwide, as it is believed to be inexpensive, easily accessible, and the confidence reposed in it stems from ancestral experience (Nwafor et al., 2005).

In light of the positive reports about Citrus paradisi in the literature, it would be a worthwhile venture to examine the potential health benefits that could result from exploring the possible therapeutic effects.

Hepatotoxicity can be defined as injury to the liver that is associated with impaired liver function caused by exposure to a drug or another non-infectious agent. The distinction between injury and function is essential because it is mainly when function is impaired that symptoms and clinically significant disease follow. Agents with recognized hepatotoxicity include carbon tetrachloride, alcohol, dantrolene sodium, valproic acid, and isonicotinic acid hydrazide.

2.0 MATERIALS AND METHODS

Dried seeds of *Citrus paradisi* were used in this study. They were collected from February to April 2015 from various vendors in Lagos. The identification of the plant was based on earlier botanical identification and voucher specimen referencing as done by Adeneye (2008).

Animals: Wistar rats of both sexes weighing between 150 and 250g were used in this study. They were procured from the breeding stock maintained at the Animal House of the College of Medicine, University of Lagos, and housed in well-ventilated plastic cages in the Animal House of the Lagos State University College of Medicine, Ikeja. The rats were maintained under standard natural photoperiodic conditions of 12 hours of light alternating with 12 hours of darkness, with a room temperature of between 25 and 26 °C and a humidity of 65±5%. They were fed with rat chow and allowed access to drinking water until they were grouped into the various experimental groups. Before experimentation, the animals were allowed to grow and acclimate for three months. Throughout the experimentation period, procedures involving the animals and their care were conducted in accordance with the guidelines for the care of Laboratory Animals in Biomedical Research, as promulgated by the Canadian Council on Animal Care.

Methods

2.1. Preparation of Aqueous Seed Extract of *Citrus paradisi*

Mature, ripe grapefruits (*Citrus paradisi*) were cut into pieces, and the seeds were mechanically separated. The seeds were thoroughly and gently rinsed in distilled water several times at room temperature. The washed seeds were drained, and the water films adhering to the seeds were blotted out with the aid of a a kitchen towel. The seeds were completely dried in an oven set at 45°C, and 300g of the dried seeds were reduced to a powdered substance by grinding. The grounded seeds were soaked in distilled water at 4 °C for 48 hours. Following which, it was filtered through a Whatman No. 1 filter paper. The filtrate was evaporated *in vacuo* to yield a dark, yellowish solid crude mass, which was stored in a desiccator until it was ready for use.

2.2. Experimental Design and Grouping of Animals

I = rats pretreated with 1ml/kg of 0.9% normal saline.
II =rats treated with 3ml/kg of 30% carbon tetrachloride before oral treatment with 10ml/kg of normal saline.
III =rats treated with 3ml/kg of 30% carbon tetrachloride before 125mg/kg of aqueous seed extract of *Citrus paradisi* in 0.9% normal saline.
IV = rats treated with 3ml/kg of 30% carbon tetrachloride before 250mg/kg of aqueous seed extract of *Citrus paradisi* in 0.9% normal saline.
V = rats treated with 3ml/kg of 30% carbon tetrachloride before 500mg/kg of aqueous seed extract of *Citrus paradisi* in 0.9% normal saline.

2.3.Induction of Carbon Tetrachloride-Induced Hepatotoxicity/Nephrotoxicity

The drug-induced hepatic/renal toxicity model used in the conduct of this study was done using 30% carbon tetrachloride dissolved in olive oil according to the modified method of Lu *et al.* (2002). Animals were injected intraperitoneally (*i.p.*) with 30% carbon tetrachloride dissolved in olive oil at a dose of 3 ml/kg body weight to induce hepatotoxicity and nephrotoxicity. Appropriate treatments followed this.

2.4. Grouping of Animals and Oral Treatment with Aqueous Seed Extract of *Citrus paradisi*

The animal model employed in this study conformed to the guiding principles for research involving animals as recommended by the Declaration of Helsinki and the Guiding Principles in the Care and Use of Animals (American Physiological Society,2002). In this curative model of hepatotoxicity and nephrotoxicity, rats were randomly divided into five groups (I-Vl) of five rats each, such that the weight differences within and between groups did not exceed ±20%. Group I rats consist of rats pretreated with 1 ml/kg of 0.9% normal saline given intraperitoneally (*i.p.*). In comparison, group II rats were intraperitoneally treated with 3 ml/kg of 30% CCl_4 1 hour before oral treatment with 10ml/kg of normal saline, Group III rats are pretreated withn3ml/kg of 30% carbon tetrachloride before oral treatment with 10ml/kg of ascorbic acid in. 9% normal saline. While groups IV- Vl rats were intraperitoneally treated with 125 mg/kg, 250 mg/kg, and 500 mg/kg of aqueous seed extract of *Citrus paradisi*, respectively, all dissolved in 0.9% normal saline. (Table 1). All treatments lasted 7 days. Twenty-four hours after the last treatment on day 7, the rats were sacrificed humanely under diethyl ether anesthesia. Ascorbic acid, being a known potent antioxidant, was used as a standard reference drug.

Table 1: Curative effect of Aqueous Seed Extract of *Citrus paradisi* against Carbon Tetrachloride-induced hepatic and renal toxicities in Wistar rats

Groups	Treatments
Group I	1 ml/kg of 0.9% normal saline *i.p.* hour before 10 ml/kg of 0.9% normal saline *p.o.*
Group II	3 ml/kg of 30% CCl_4 in olive oil *i.p.* 1 hour before 10 ml/kg of 0.9% normal saline *p.o.*
Group III	3ml/kg of 30% carbon tetrachloride before oral treatment with 10ml/ kg of ascorbic acid in 0.9% normal saline.
Group IV	3 ml/kg of 30% CCl_4 in olive oil *i.p.,* 1 hour before 125 mg/kg of aqueous seed extract of Citrus paradisi in 0.9% normal saline *p.o.*

Group V	3 ml/kg of 30% CCl_4 in olive oil *i.p.,* 1 hour before 250 mg/kg of aqueous seed extract of Citrus paradisi in 0.9% normal saline *p.o.*
Group VI	3 ml/kg of 30% CCl_4 in olive oil *i.p.,* 1 hour before 500 mg/kg of aqueous seed extract of Citrus paradisi in 0.9% normal saline *p.o.*

2.5. Animal Sacrifice and Collection of Blood Samples

Before sacrifice, animals were fasted for 24 hr. The fasted animals were anesthetized by placing them in a closed jar containing cotton wool soaked with diethyl ether anesthetic. Following anesthesia, blood samples were collected through cardiac puncture into plain sample bottles (for serum preparation) and heparinized tubes (for plasma preparation).

2.5.1. Preparation of Serum

Blood samples collected in plain sample bottles were allowed to clot at room temperature for 6 hours before they were centrifuged using a Uniscope Laboratory Centrifuge (Model SM 902V, Surgifriend Medicals, England) at 3000 rpm for 20 minutes to allow the serum to separate. The clear sera portions were aspirated off, and the residues discarded. The separated sera were stored in a wet-frozen state until ready for use.

2.5.2. Preparation of Plasma

Blood samples collected in heparinized tubes were centrifuged using a Uniscope Laboratory Centrifuge (Model SM 902V, Surgifriend Medicals, England) at 3000 rpm for 1 hr. to sediment the blood cells. The clear plasma was aspirated off, and the residue discarded. The plasma produced was stored in a wet-frozen state until ready for use.

2.5.3. Excision of Organs

Following bleeding the animals by cardiac puncture, the entire bodies of the animals were swabbed with cotton wool soaked with ethanol. After this, the abdominal cavities of the animals were opened through a midline abdominal incision to expose the abdomen, allowing for the excision of the kidney and liver. The excised kidney and liver samples were washed thoroughly in ice-cold normal saline several times to remove gross fat and blood. The thoroughly washed kidney/liver samples were then stored wet-frozen at -80 $^{\circ}$C in a Revco freezer until ready to use.

3. RESULTS

3.1. Effect of serum malondialdehyde in Treated, Normal, and Untreated hepatotoxic rats.

Figure 3.1 summarizes the effect of serum malondialdehyde in treated, normal, and untreated hepatotoxic rats. Single intraperitoneal treatment of a rat with carbon tetrachloride causes a significant elevation in serum malondialdehyde (Group II) when compared with controls (Group I). Treatment with a graded dose of *Citrus paradisi* (250mg-500mg/kg body weight) caused a significant reduction in serum malondialdehyde in a dose-dependent manner (Group IV-VI).

3.2. Effect of liver malondialdehyde in Treated, Normal, and Untreated hepatotoxic rats.

Figure 3.2 summarizes the effect of liver malondialdehyde in treated, normal, and untreated hepatotoxic rats. Treatment with carbon tetrachloride resulted in a significant increase in liver malondialdehyde levels (Group II) compared to the control group (Group I). There was a significant reduction in the level of liver malondialdehyde (Group III) when treated with ascorbic acid. In the same reaction, aqueous seed extract of *Citrus paradisi* (250mg-500mg/kg body weight) significantly reduces the

liver malondialdehyde level (Group IV-VI) but not dose-dependently.

3.3.Effect of serum glutathione in Treated, Normal, and Untreated hepatotoxic rats.

Figure 3.3 summarizes the effect of serum glutathione in treated, normal, and untreated hepatotoxic rats. Serum reduced glutathione was significantly reduced by carbon tetrachloride intoxication (Group II) while vitamin C caused a significant increase (group III) when compared with the controls (Group I). Oral graded dose of *Citrus paradisi* (125-500mg/kg body weight). (Group IV-VI) also significantly elevates reduced serum glutathione dose-dependently.

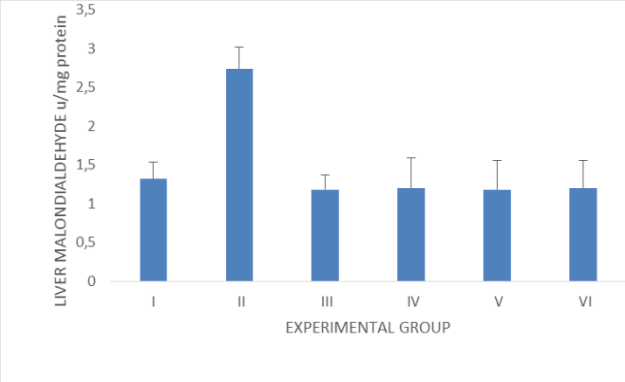

FIGURE 3.1: Serum malondialdehyde in Treated, Normal, and Untreated hepatotoxic rats.

Each value was represented as Mean ± SEM
I = rats pretreated with 1ml/kg of 0.9% normal saline.
II =rats treated with 3ml/kg of 30% carbon tetrachloride before oral treatment with 10ml/kg of normal saline.
III = rats treated with 3ml/kg of 30% carbon tetrachloride before oral treatment with 10ml/kg of ascorbic acid in 0.9% normal saline.
IV =rats treated with 3ml/kg of 30% carbon tetrachloride before 125mg/kg of aqueous seed extract of *Citrus paradisi* in 0.9% normal saline.
V = rats treated with 3ml/kg of 30% carbon tetrachloride before 250mg/kg of aqueous seed extract of *Citrus paradisi* in 0.9% normal saline.
VI = rats treated with 3ml/kg of 30% carbon tetrachloride before 500mg/kg of aqueous seed extract of *citrus paradisi* in 0.9% normal saline.

3.4.Effect of liver glutathione in Treated, Normal, and Untreated hepatotoxic rats.

Figure 3.4 summarizes the effect of liver glutathione in treated, normal, and untreated hepatotoxic rats. The results of the liver's reduced glutathione also followed the same trend as those of the serum.

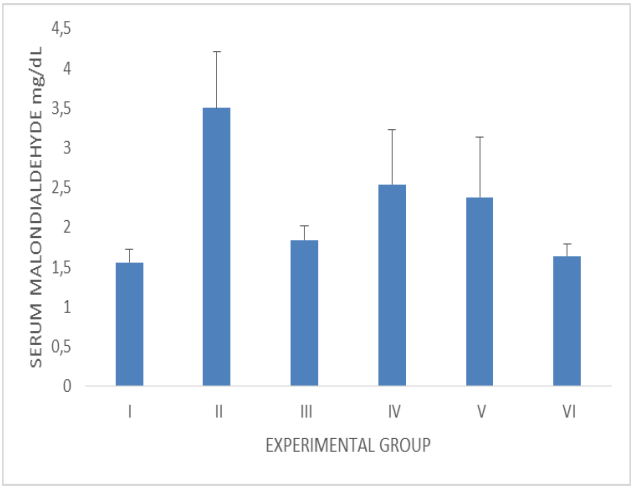

FIGURE 3.2: The levels of liver malondialdehyde in Treated, Normal, and Untreated hepatotoxic rats.

Each value was represented as Mean ± SEM
I = rats pretreated with 1ml/kg of 0.9% normal saline.
II = rats treated with 3ml/kg of 30% carbon tetrachloride before oral treatment with 10ml/kg of normal saline.
III = rats treated with 3ml/kg of 30% carbon tetrachloride before oral treatment with 10ml/kg of ascorbic acid in 0.9% normal saline.
IV= rats treated with 3ml/kg of 30% carbon tetrachloride before 125mg/kg of aqueous seed extract of *Citrus paradisi* in 0.9% normal saline.
V = rats treated with 3ml/kg of 30% carbon tetrachloride before 250mg/kg of aqueous seed extract of *Citrus paradisi* in 0.9% normal saline.

VI = rats treated with 3ml/kg of 30% carbon tetrachloride before 500mg/kg of aqueous seed extract of *Citrus paradisi* in 0.9% normal saline.

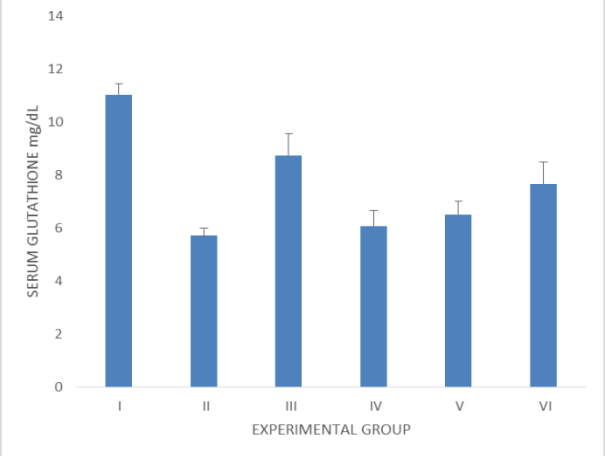

FIGURE 3.3: serum Glutathione in Treated, Normal, and Untreated hepatotoxic rats.

Each value was represented as Mean ± SEM
I = rats pretreated with 1ml/kg of 0.9% normal saline.
II = rats treated with 3ml/kg of 30% carbon tetrachloride before oral treatment with 10ml/kg of normal saline.
III = rats treated with 3ml / kg of 30 % carbon tetrachloride before oral treatment with 10ml / kg of ascorbic acid in 0.9% normal saline.
IV = rats treated with 3ml/kg of 30% carbon tetrachloride before 125mg/kg of aqueous seed extract of *Citrus paradisi* in 0.9% normal saline.
V = rats treated with 3ml/kg of 30% carbon tetrachloride before 250mg/kg of aqueous seed extract of *Citrus paradisi* in 0.9% normal saline.
VI= rats treated with 3ml/kg of 30% carbon tetrachloride before 500mg/kg of aqueous seed extract of *Citrus paradisi* in 0.9% normal saline.

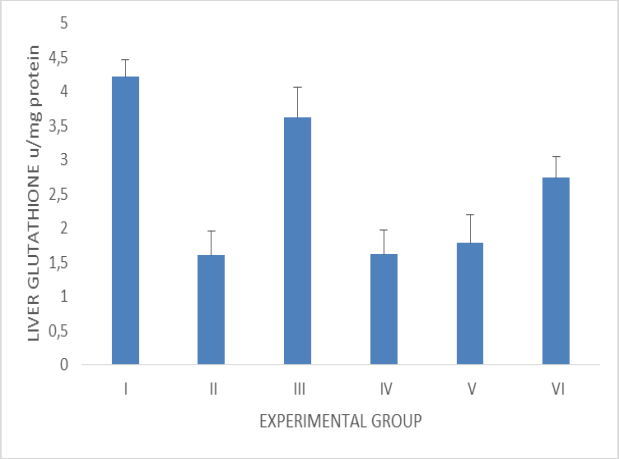

FIGURE 3.4: Liver Glutathione in Treated, Normal, and Untreated hepatotoxic rats.

Each value was represented as Mean ± SEM
I = rats pretreated with 1ml/kg of 0.9% normal saline.
II=rats treated with 3ml/kg of 30% carbon tetrachloride before oral treatment with 10ml/kg of normal saline.
II I=rats treated with 3ml/kg of 30% carbon tetrachloride before 125mg/kg of aqueous seed extract of *Citrus paradisi* in 0.9% normal saline.
IV = rats treated with 3ml/kg of 30% carbon tetrachloride before 250mg/kg of aqueous seed extract of *Citrus paradisi* in 0.9% normal saline.
V = rats treated with 3ml/kg of 30% carbon tetrachloride before 500mg/kg of aqueous seed extract of *Citrus paradisi* in 0.9% normal saline.

4. DISCUSSION

Reactive oxygen species (such as hydrogen peroxide, hydroxide, and oxygen, collectively known as ROS) play essential physiological functions and can also cause extensive cellular damage. Cells are equipped with efficient molecular strategies to precisely control the intracellular ROS level and maintain a balance between oxidant and antioxidant molecules. Oxidative stress, resulting from an imbalance between the generation of ROS and the antioxidant defense capacity of the cell, affects major cellular components, including lipids, proteins, and DNA. This phenomenon is closely

associated with several human disorders, such as many degenerative diseases, including cardiovascular disease, diabetes, cancer, and neurodegenerative disorders (Bray,1999), and with almost all liver pathologies (Kang et al., 2002). All these conditions appear to be primarily related to chronic oxidative stress. However, acute exposure to high levels of ROS also seems to be responsible for the development of various damage, such as during ischemia/reperfusion (I/R) in the the liver. Besides producing cell damage, ROS can also be considered molecular second messengers within the cell, as they are generated during the triggering of particular cellular responses by cytokines, hormones, growth factors, and other soluble mediators, such as extracellular ATP. Therefore, ROS represents a double-edged sword and can act either positively or negatively on cell functioning, depending on the intensity and duration of the oxidative stress produced in a cell. It is therefore not surprising that the role of ROS is either as apoptotic molecules or as stimulators of cell proliferation, depending on the cell type and the intensity of the stress produced.

Inflammation begins when tissues react to a local irritation, usually caused by a physical injury, by infection, or by exposure to a toxicant. Fluid and accompanying white blood cells traverse the vascular barrier, leading to swelling, erythema, further inflammation, and the attraction of additional white blood cells. The solution phase of inflammation involves repair and cell proliferation, ultimately leading to tissue regeneration. During the inflammatory phase, a burst of respiration occurs, leading to the creation and release of free radicals, including the the production of both reactive oxygen species (ROS) and reactive nitrogen species (RNS). ROS and RNS utilize three main pathways of signaling, which result in damage to DNA, proteins, and lipids. Lipid peroxidation triggers the arachidonic acid cascade, leading to the production of cell proliferation-stimulating eicosanoids. While free radicals induce DNA damage directly, by-products of the arachidonic acid pathway, such as malondialdehyde (MDA) and 4-hydroxynonenal (4-HNE), also act as DNA-damaging agents.

In the present study, the effects of carbon tetrachloride intoxication on liver and serum malondialdehyde and reduced glutathione were evaluated, and the ability of the aqueous seed extract of Citrus paradisi to ameliorate the deleterious effects of carbon tetrachloride was also assessed. All the effects of reactive oxygen species highlighted above apply to carbon tetrachloride, as its deleterious effects are mediated through reactive oxygen species. In the present study, carbon tetrachloride intoxication resulted in a significant decrease in both serum and liver reduced glutathione levels (Figs. 3.3 and 3.4), while both liver and serum malondialdehyde levels were significantly elevated (Figs. 3.1 and 3.2). It is expected in an organism that has been stressed oxidatively.

However, treatment with a graded oral dose of aqueous seed extract of *Citrus paradisi* attenuated the toxic effects of carbon tetrachloride at all the doses tested. While the level of reduced glutathione was significantly increased, that of malondialdehyde was significantly reduced. The reduction observed may not be unconnected with the presence of active principles in the extract that possess antioxidants or agents that are capable of scavenging the free radicals.

5. CONCLUSION

The present study has established that Citrus paradisi possesses antioxidant properties and can also scavenge reactive oxygen species in the face of mounting oxidative stress. Previous reports have indicated the presence of active phytochemical components in Citrus paradisi that exhibit antioxidant properties responsible for the attenuating effects in carbon tetrachloride toxicity, as reported in this study. It is hoped that with further work, this extract may become useful in the management or treatment of

oxidative stress to prevent or manage degenerative diseases.

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LENGTH-WEIGHT RELATIONSHIP AND ITS IMPLICATIONS ON *HETEROBRANCHUS BIDORSALIS* FED PROCESSED INSECTS AS PROTEIN SOURCE.

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Abstract
The growth performance and length-weight relationship (LWR) of cultured fish are critical indicators of aquaculture productivity and fish health. This study aimed to assess the morphometric traits and implications on the LWRs of *Heterobranchus bidorsalis* fish fed with Black Soldier Fly Larvae (BSFL) for 10 weeks. They were reared under five different treatment conditions (T_1 – 0%BSFL, T_2 – 25%BSFL, T_3 – 50%BSFL, T_4 – 75%BSFL and T_5 – 100BSFL). A total of 360 fish were sampled, and data on length and weight were collected and analyzed using descriptive statistics and regression models. The results showed notable variations across treatments, with mean lengths ranging from 17.01 cm (T_2R_1) to 21.48 cm (T_5R_2) and mean weights ranging from 42.71 g (T_5R_2) to 66.67 g (T_3R_2). Most replicates exhibited strong, statistically significant positive correlations between length and weight ($p < 0.05$), with R^2 values above 0.70, indicating consistent growth patterns. However, one replicate (Y_5R_2 -100%BSFL) demonstrated a weak and non-significant LWR ($R^2 = 0.029$, $p = 0.428$). Regression exponent values ("b") varied across treatments, with most groups exhibiting negative allometric growth ($b < 3$), indicating that the fish increased in length more rapidly than in weight. The findings highlighted the influence of treatment conditions, as T_3 (50% BSFL) emerged as the most promising treatment, achieving optimal length and weight gain, alongside the control with 0% BSFL. The study concluded that LWR analysis is an effective, non-invasive tool for monitoring fish growth and guiding management practices.

Keywords: Length-weight relationship, Fish growth, Allometric analysis, Aquaculture management, Morphometrics

1. Introduction

Aquaculture continues to play a crucial role in meeting the increasing global demand for animal protein, with freshwater fish production serving as a cornerstone of food security in many developing nations (FAO, 2022). The efficiency of aquaculture systems largely depends on the ability to monitor and optimize fish growth under varying environmental and management conditions. Among the most widely used non-invasive

methods for evaluating fish growth and condition is the analysis of **length-weight relationships (LWRs).** This relationship is vital for estimating fish biomass, understanding growth patterns, and assessing the health status of cultured species (Adeyemi et al., 2021; Mousavi-Sabet et al., 2023).

The LWR provides insights into growth dynamics. When the exponent "**b**" approximates 3, fish exhibit **isometric growth,** where weight increases proportionally with length. Values of **b < 3** or **b > 3** reflect **allometric growth,** indicating disproportionate changes in body form or energy allocation (Rahman et al., 2022). LWRs are influenced by several factors, including genetics, nutrition, water quality, stocking density, and husbandry practices (Yılmaz et al., 2020; Nuhu et al., 2023). Recent research has emphasized the need for localized studies on LWRs, particularly under varying treatment or experimental conditions, to guide evidence-based decisions in aquaculture operations (Onyia et al., 2021). Moreover, monitoring LWRs across multiple replicates helps detect outliers or irregular patterns in growth, which may indicate stress, disease, or environmental fluctuations (Bello-Olusoji et al., 2022). This study investigated the length-weight relationships of fish reared under five different treatments and their implications. It was achieved by evaluating the growth patterns, determining the strength of length-weight associations, and identifying any deviations across the treatments. The results aimed to inform optimized management strategies for enhancing fish growth performance in aquaculture systems.

2. Materials and methods

2.1 Experimental setup

The experiment was conducted at the Multidisciplinary Research Laboratory complex of Osun State University. The culture tanks were arranged in parallel, having a separate inlet and outlet. A total of 250 individuals were first acclimatized for 7 days and then randomly distributed into 30 tanks, with 25 fish individuals per tank. The tanks were dark in colour with dimensions 3m x 2m x 2m deep. Water was constantly maintained at a 1.5m level and covered with nets.

2.2 Experimental treatments

A total of 5 treatments, varying in the inclusion of black soldier fly larvae (BSFL), were introduced into the diet, with three replicates per treatment in a completely randomized design. The distribution is as follows:

T_1 (T_1R_1, T_1R_2, T_1R_3) – no inclusion of BSFL (100% fishmeal)

T_2 (T_2R_1, T_2R_2, T_2R_3) – 25% inclusion of BSFL (75% fishmeal)

T_3 (T_3R_1, T_3R_2, T_3R_3) – 50% inclusion of BSFL (50% fishmeal)

T_4 (T_4R_1, $T4R_2$, T_4R_3) – 75% inclusion of BSFL (25% fishmeal)

T_5 (T_5R_1, T_5R_2, T_5R_3) – 100% inclusion of BSFL (0% fishmeal)

2.3 Sampling method

Samples of *Heterobranchus bidorsalis* were taken fortnightly for 6 months. Fish to be measured were collected randomly from each tank using hand nets between 0700 and 0900 hours. The fish were carefully handled to avoid stress.

2.4 Morphometric characteristics

The length of the randomly chosen fish from each tank was measured using a measuring board calibrated in centimeters (cm) and measured from the tip of the mouth to the end of the caudal fin. The weight was measured using a digital, sensitive scale, and readings were taken when the digital meter was steady, measured in grams (g).

2.4.1 Length-weight relationship

The relationship between length (L) and weight (W) was calculated as expressed by Le Cren (1951) and expressed in equations I and II:

$$W = aL^b \quad \text{---------- equation I}$$

$$Log\ W = log\ a + b \log L \quad \text{---------- equation II}$$

Where: W/ log W = weight (g)
L/ log L = Length (cm)
a & b = regression coefficient and slope

2.4.2 Condition factor (K)

It was estimated by the relationship expressed in equation III.

$$K = \frac{W\ x\ 1000}{L^3}$$ ---------- equation III

Where: K = condition factor
L = Total length (cm)
W = weight of fish (g)

2.5 Statistical analysis

All statistical analyses were conducted at a $p < 0.05$ significance level using SPSS 20.0 statistical software. The data on fish length and weight were presented using simple descriptive analysis.

3. Results and discussion

3.1 Descriptive relationships

The descriptive analysis across treatments (Table 1) shows variability in fish growth performance, with mean lengths ranging from **17.01 cm (T_2R_1)** to **21.48 cm (T_5R_2)** and mean weights from **42.71 g (T_5R_2)** to **66.67 g (T_3R_2).** The wide variation in weight, especially the maximum value of 235g in **T3R3,** highlighted the potential influence of environmental conditions, feed efficiency, or genetic differences among fish. Such variability in length and weight within and across replicates is common in aquaculture systems and can be attributed to differences in stocking density, water quality, feed composition, and handling stress (Rahman et al., 2022; Sogbesan & Ugwumba, 2023).

The differences in average weights and lengths among treatments likely reflected the varying efficiency of experimental conditions such as diet formulation, water quality, or genetic factors (Kolding et al., 2008; De Silva & Anderson, 1995). For instance, T_3R_2 (T_3) achieved the highest mean weight (66.67 g), which indicated favorable conditions. In contrast, T_5R_2, despite the highest mean length (21.48 cm), recorded one of the lowest weights (42.71 g), suggesting suboptimal nutrient conversion or stress, which may lead to elongation without corresponding biomass gain (Ali et al., 2000).

Table 1: Descriptive analysis for length and weight across the treatments

	N Statistic	Minimum Statistic	Maximum Statistic	Mean Statistic	Std. Error
T_1R_1 L	24	12.6	24.5	18.667	0.8525
T_1R_1 W	24	14.7	103.2	59.1	6.3824
T_1R_2 L	24	11.9	24.4	17.383	0.7901
T_1R_2 W	24	1.5	99.3	48.613	5.7321
T_1R_3 L	24	12.2	22.8	17.6	0.7992
T_1R_3 W	24	12.7	100.2	50.217	6.2938
T_2R_1 L	24	11	26	17.01	0.875
T_2R_1 W	24	8	136	51.19	7.378
T_2R_2 L	24	12	26	17.77	0.866
T_2R_2 W	24	12	129	45.48	6.112
T_2R_3 L	24	13	25	17.75	0.77
T_2R_3 W	24	13	102	50.63	5.769
T_3R_1 L	24	12	25	17.77	0.839
T_3R_1 W	24	15	110	53.39	5.886
T_3R_2 L	24	12	27	19.68	0.802
T_3R_2 W	24	28	147	66.67	6.99
T_3R_3 L	24	11	28	17.89	0.914

T_3R_3 W	24	10	235	57.4	10.586
T_4R_1 L	24	12	22	17.57	0.645
T_4R_1 W	24	13	86	47	4.651
T_4R_2 L	24	10	26	17.48	0.804
T_4R_2 W	24	12	129	47.93	5.48
T_4R_3 L	24	12	23	17.55	0.678
T_4R_3 W	24	13	83	46.59	4.576
T_5R_1 L	24	13	24	18.23	0.742
T_5R_1 W	24	18	112	54.69	6.23
T_5R_2 L	24	10	135	21.48	5.003
T_5R_2 W	24	6	95	42.71	4.78
T_5R_3 L	24	12	29	17.78	0.842
T_5R_3 W	24	14	89	48.72	5.277

3.2 Length-weight relationship

The regression analysis (Table 2) and plots (Figures 1–15) showed that most treatments exhibited a significant ($p < 0.05$) and positive length-weight relationship, with coefficient of determination (R^2) values ranging from 0.745 to 0.938, indicating a strong predictive power between body length and weight. It was observed that **Y_1R_1 ($R^2 = 0.938$)** and **Y_2R_3 ($R^2 = 0.911$)** showed powerful linear associations, confirming consistent growth trends in these groups. Only **Y_5R_2** displayed a non-significant LWR **($p = 0.428$; $R^2 = 0.029$),** which may be due to stress, inconsistent feeding, or feed treatment (Olapade et al., 2021; Bello et al., 2022). Such inconsistencies can distort morphometric models and must be carefully monitored. The **regression exponent "b"**, which determines the type of growth pattern, varied widely. Most values fell below 3, indicating **negative allometric growth,** where fish increase more in length than in weight (Froese, 2006; Okereke & Nwani, 2020). A few treatments, such as **Y_1R_1 ($b = 7.251$),** exhibited extremely high values suggestive of measurement bias or unusually rapid weight gain, possibly due to high-energy feed or hormonal influence.

Negative allometric growth patterns predominate in aquaculture systems where fish have limited access to high-quality protein or are subjected to suboptimal rearing conditions (Bukar et al., 2024; Nuhu et al., 2023). In this study, the lower "b" values in most groups suggest that the fish may have experienced nutritional constraints or stressors, leading to elongated body shapes without proportional weight gain. The presence of **substantial and significant LWRs in most replicates** confirms the reliability of length-weight analysis for monitoring fish condition. According to Adeyemi et al. (2021), high R^2 values (>0.80) are indicative of uniform growth and good fish health. Moreover, comparing replicates within treatments highlights the repeatability of growth performance, which is critical in determining the most effective culture protocols. The **superior performance in T3R2 (T_3 -** 50% BSFL) is evident, with the highest mean weight (66.67 g) and a strong linear regression ($R^2 = 0.810$), suggesting a favorable combination of management factors in this treatment. This group may serve as a benchmark for future trials or scaling up. Conversely, groups like **T_5R_2,** which showed a high mean length (21.48 cm) but lower weight and poor LWR, require further investigation.

Length-weight relationships are essential tools for monitoring fish growth, especially in resource-limited settings where advanced analytical methods are not always available. The ability to predict body condition from simple morphometric measurements supports regular monitoring and

early intervention when growth deviations are observed (Onyia et al., 2021; Mousavi-Sabet et al., 2023). The study highlights the importance of treatment-specific management, encompassing feed formulation, water quality control, and genetic selection, in achieving optimal growth. Furthermore, treatment replicability, as evident in the consistency between replicates such as Y4R1 and Y4R3, enhances confidence in scaling up the most successful culture practices.

Table 2: Summary of length-weight relationship across the treatments.

Variables	a	B	Relationship	p-value	R^2 value	Figures
Y_1R_1 L & W	1.882	7.251	Direct	0.000*	0.938	Figure 1
Y_1R_2 L &W	1.045	0.129	Direct	0.000*	0.883	Figure 2
Y_1R_3 L & W	1.080	0.111	Direct	0.000*	0.764	Figure 3
Y_2R_1 L & W	1.058	0.109	Direct	0.000*	0.847	Figure 4
Y_2R_2 L &W	1.107	0.109	Direct	0.000*	0.596	Figure 5
Y_2R_3 L & W	1.049	0.129	Direct	0.000*	0.911	Figure 6
Y_3R_1 L & W	1.032	0.131	Direct	0.000*	0.849	Figure 7
Y_3R_2 L &W	1.107	0.103	Direct	0.000*	0.810	Figure 8
Y_3R_3 L & W	1.134	0.075	Direct	0.000*	0.745	Figure 9
Y_4R_1 L & W	1.047	0.128	Direct	0.000*	0.858	Figure 10
Y_4R_2 L &W	1.057	0.127	Direct	0.000*	0.746	Figure 11
Y_4R_3 L & W	1.046	0.138	Direct	0.000*	0.871	Figure 12
Y_5R_1 L & W	1.097	0.105	Direct	0.000*	0.773	Figure 13
Y_5R_2 L &W	1.143	0.177	Direct	0.428	0.029	Figure 14
Y_5R_3 L & W	1.008	0.143	Direct	0.000*	0.804	Figure 15

* indicates significance at $p<0.05$, a – regression constant, b – regression value, R^2 – regression magnitude, L – length, W - weight

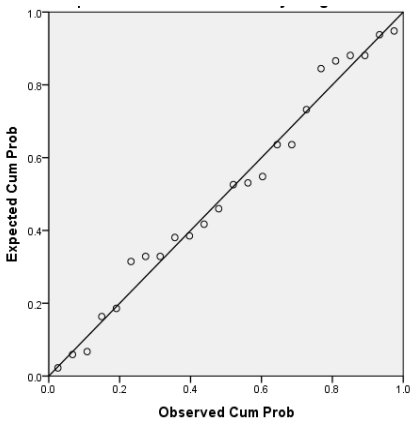

Figure 1: Plot of length and weight in Y_1R_1

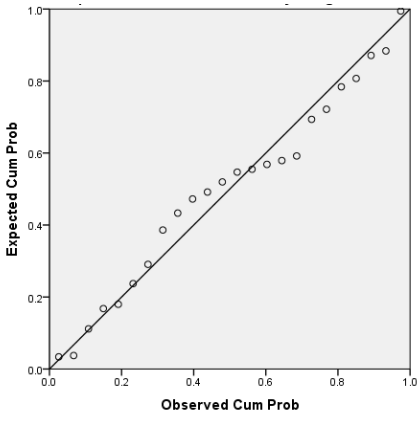

Figure 2: Plot of length and weight in Y_1R_2

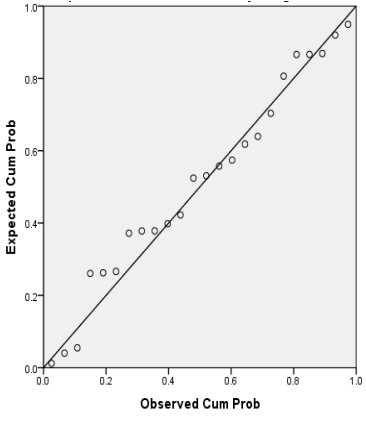

Figure 3: Plot of length and weight in Y_1R3

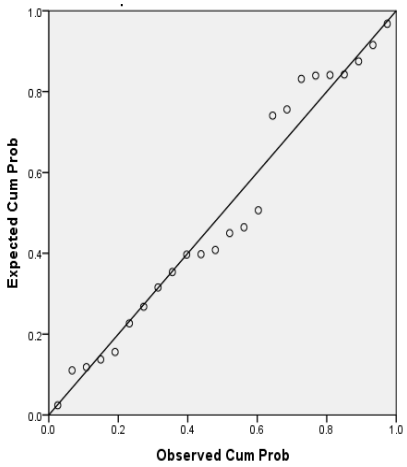

Figure 4: Plot of length and weight in Y_2R_1

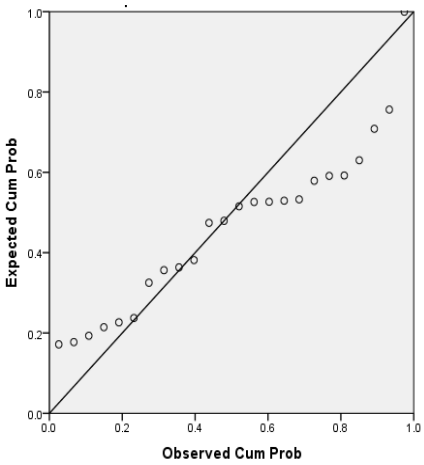

Figure 5: Plot of length and weight in Y_2R_2

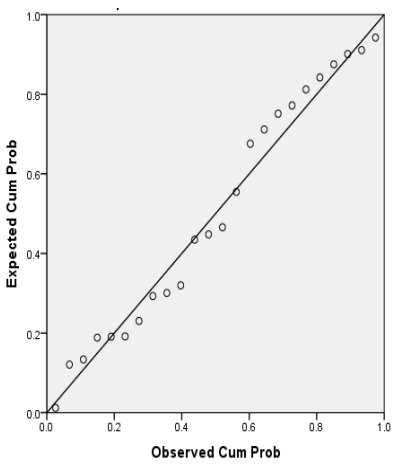

Figure 6: Plot of length and weight in Y_2R3

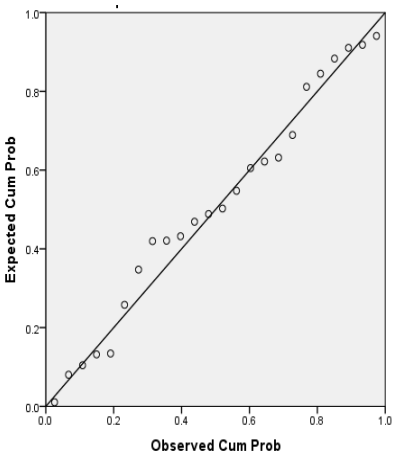

Figure 7: Plot of length and weight in Y_3R_1

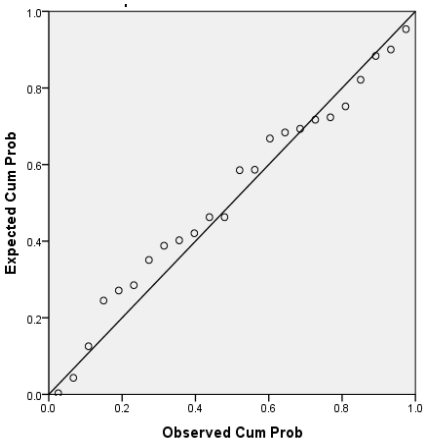

Figure 8: Plot of length and weight in Y_3R_2

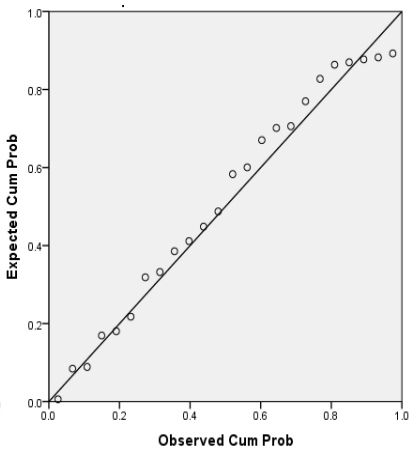

Figure 9: Plot of length and weight in Y_3R_3

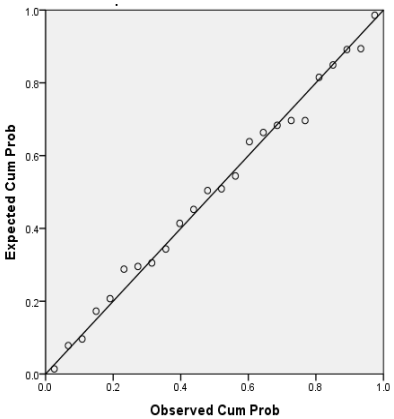

Figure 10: Plot of length and weight in Y_4R_1

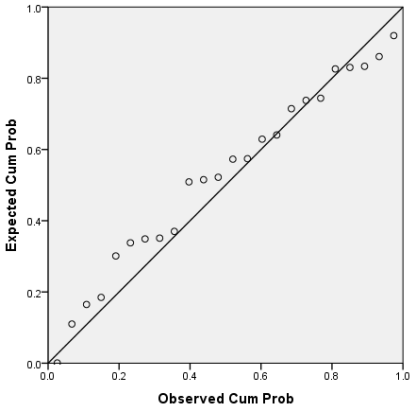

Figure 11: Plot of length and weight in Y_4R_2

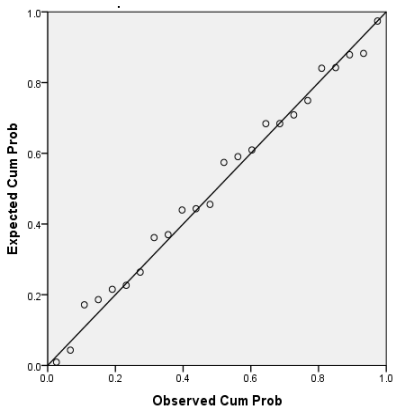

Figure 12: Plot of length and weight in Y_4R_3

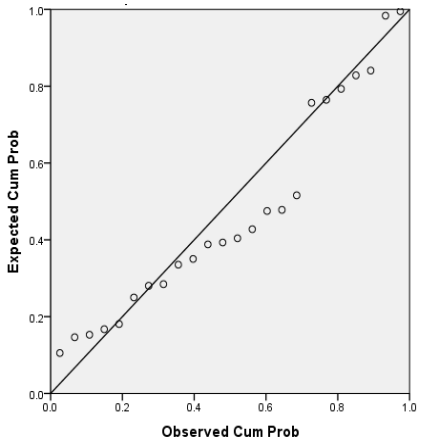

Figure 13: Plot of length and weight in Y_5R_1

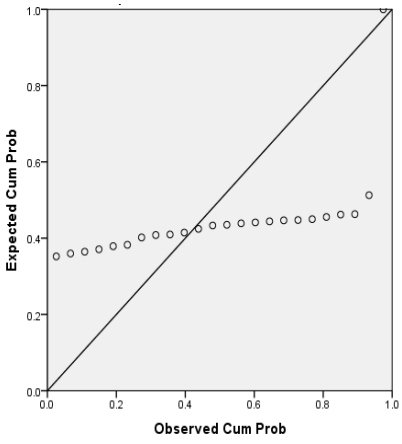

Figure 14: Plot of length and weight in Y_5R_2

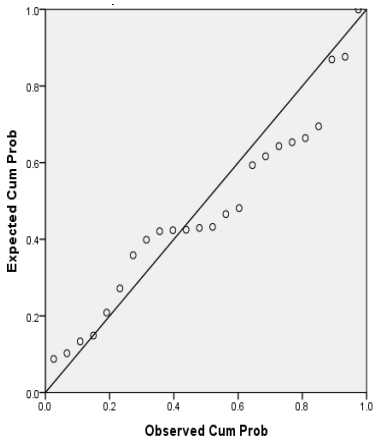

Figure 15: Plot of length and weight in Y_5R_3

Conclusion

This study evaluated the length-weight relationships and growth performance of fish across different treatment replicates. The findings revealed considerable variation in growth metrics among treatments, with T_3R_2 showing the highest mean weight, and T_5R_2 the highest mean length. Most treatment groups exhibited significant and strong positive length-weight relationships, confirming the reliability of morphometric indicators in assessing fish growth. However, anomalies such as the extremely low R^2 in Y_5R_2 suggest inconsistencies that could be due to environmental, nutritional, or methodological factors. The regression analysis also highlighted that, while the majority of fish exhibited direct growth patterns, the wide range of "b" values indicates diverse growth dynamics across treatments—some potentially influenced by factors such as feed quality, stocking density, or water conditions. The significant variation in growth responses underscores the importance of optimizing culture conditions to improve productivity and fish health.

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WILDLIFE MANAGEMENT AND BLUE ECONOMY IN THE ERA OF CLIMATE CHANGE MANAGING CANNIBALISM IN GRASSCUTTERS (*THRYONOMIS SWINDERIANUS* TEMMINCK) REARED IN CAPTIVITY

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Abstract
Cannibalism, the eating of any animal by another member of the same species, has the advantage of regulating population numbers. Still, on the other hand, it also decreases the expected survival rate of the whole population. Five bucks, paired with ten female grasscutters and sixty-one kits littered, were used for the study to ascertain the causes of cannibalism in captive rearing. The paired animals were housed in floor hutches. They were fed ad libitum a mixture of elephant grass, formulated concentrate supplement, multivitamin, and water. Results showed that four out of sixty-one neonates, representing 6.56%, were cannibalized within the first three days, while ten, representing 16.39%, were cannibalized on the same day as littering. All cannibalism took place at night, with only the head regions eaten. However, the administration of salt lick and bone meal helped to stabilise the losses. This study is aimed at discussing the various ways cannibalism in captive rearing of grasscutters can be reduced or prevented.
Keywords: Cannibalism, Grasscutter, Nursing, Multiplication, Food Security.

Introduction

Polis (1981) defined cannibalism as an everyday ecological interaction that is practiced by more than 1,500 species in the animal kingdom. It is the act of consuming another individual of the same species as food. Nutritional imbalance, as reported by Elgar and Crespi (1992), is a major precursor of cannibalism. It frequently serves as a mechanism to control the population or to ensure the genetic combination of an individual. Cannibalism is one of the recognisable forms of abnormal behaviour observed in animals. Frazer (1994) reported that forms of abnormal behavior are related to noxious stimuli or stressors in the animal environment. Various factors contribute to cannibalism, including the feeding behavior of animals, nutritional deficiency, starvation, overcrowding, improper stocking rates, anomalous maternal behavior, decline in environmental quality, and poor management practices.

The grasscutter, also known as the cane rat (Thryonomys swinderianus), is a wild hystricomorph rodent endemic to Africa (Adoun, 1993). It is among several types of animals used locally and regionally for meat (Anonymous, 1993). It is the preferred and perhaps the most expensive meat in West Africa (National Research Council, 1991; Asibey and Addo, 2000). Grasscutters are polygynous, and the neonates are born precocious, like most hystricomorph rodents. The animal can be weaned at 3-4 weeks, as is already being practiced by some grasscutter farmers (Asibey, 1974a; Skinner and Smithers, 1990; Alexander, 1992). However, to ensure two deliveries per year per female, the nursing period should not exceed 6 weeks. Their gestation lasts an average of 152 days among the cane rats (Mensah and Baptist, 1986). Visual appreciation of the volume of the abdomen in a pregnant doe is not possible until late, towards about 120 days of gestation (Asibey, 1974b and Fayenuwu *et al*., 2001). The permanent mating system commonly practiced by most farmers sometimes results in cannibalism of the neonates by the males (Asibey, 1974b). There is a paucity of information on grasscutter cannibalism. This paper throws more light on the cannibalism of grasscutters by nursing does.

Materials and Methods

This study, which spanned seven months, was conducted at the Grasscutter Domestication and

Multiplication Unit of the Forestry Research Institute of Nigeria, Ibadan, Oyo State. Ten female grasscutters were paired with five males. Paired animals were housed in floor hutches and observed closely. Pregnant does were only separated from the males when there was an outright increase in body weight. They were fed ad libitum with elephant grass (*Pennisetum purpureum*) and formulated concentrate supplement. Multivitamins and water were added to the concentrate and mixed before feeding. Ambient temperature and relative humidity were regulated with the aid of a cellophane nylon hung around the building. Hutches were cleaned daily, while feeding troughs were washed twice a week. Body weights of cane rats were taken monthly.

Results and Discussion

Tables 1 and 2 show the percentage composition of forages and concentrates fed to the animals. Table 3 showed that out of sixty-one kits littered, fourteen (six males and eight females) were cannibalised. While ten kits (5 males and five females) were cannibalised on the very first day of littering, the remaining four were fed on by their mothers within the first three days after littering. It was observed that all the nursing did cannibalised only fed on the head region alone, while the remaining parts of the body of all the kits (the cervical down to the caudal regions) were untouched. The pattern of cannibalism raised concerns that the nursing home had nutritional deficiencies in calcium and other minerals. With the introduction of salt lick and bone meal in their diet, no other loss through cannibalism was recorded. The findings of the study agreed with those of MacDonald *et al.* (1998) that a lack of specific nutrients or elements in the diet of many domesticating animals may cause cannibalism. Frazer (1994) asserted that many examples of aberrant feeding behaviour, including epimelistic practices in animals, where the nursing does show repulsion of the newborn. A peculiar case was also recorded in the study, where a doe littered eight neonates and allowed them to suckle only during the daytime, to be fed one each night for three consecutive days. The neonates were weaned on the 4th day, but they refused to feed on the forage and concentrate introduced to them. They were allowed to stay with their mother from the 5th day from 8000 to 1600hours to allow them to obtain the full benefit of lactation (Cowie, 1990), after which they were separated. This procedure lasted for six weeks, after which five were successfully weaned.

Table 1: Proximate Composition of Elephant Grass (*P. purpureum*)

Parameter	Percentage composition (%)
Moisture	15.65
Crude protein	7.38
Crude fibre	29.65
Ether extract	0.42
Ash	6.45
Nitrogen-free extract	40.75

Table 2: Proximate Composition of Concentrate Supplement

Ingredient	Percentage composition (%)
Crude protein	14.76
Crude fibre	7.01
Ether extract	4.40
Metabolisable energy (kcal/g)	2422.98
Energy: protein	164:16

Table 3: Records of birth, cannibalised, and weaned grasscutters

Samples	Male	Female	Total
Number littered	28	33	61
Total number cannbalised	6	8	14
Number cannibalised in the first three days of littering	1	3	4
Number cannibalised on the first day of littering	5	5	10
Number weaned after six weeks	22	25	47

Conclusion and Recommendations

Cannibalism is a common practice in animal production, occurring particularly when there is an imbalance in nutrition. It leads to reductions and losses in animal populations. To manage the causes of cannibalism, efforts should be made to provide animals with rich and balanced nutrients for maintenance and production, as they are in captivity and cannot source their food naturally, unlike those in the wild. The practice of neonates' separation from nursing should be encouraged if cannibalism persists after taking the necessary precautions. The animals should be closely watched and culled any doe with a consistent record of cannibalising the young.

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EFFECTS OF SWEET POTATOES LEAVES MEAL (*ipomea batatas)* ON GROWTH PERFORMANCE OF BROILER CHICKENS AT STARTER PHASE (0-4 WEEKS)

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ABSTRACT
The study was carried at the poultry unit of livestock teaching and research farm in the department of animal science, Kano University of Science and Technology, Wudil, to find the effect of *Moringa* oleifera leaf meal as an additive on growth performance of Broiler Chicken. A total of one hundred (100) day old, unsexed broiler chicks of AMO farms were used in this experiment. All the chicks were allotted to five (5) treatments comprising of twenty (20) chicks per replication in complete randomized design. The treatments tested are T1 (0%), T2 (5%), T3 (10%), T4 (20%) and T5 (30%) respectively. The experiment lasted for eight (8) weeks. A day before slaughtering all the chickens were weighed and were given feed overnight, but water was supplied ad. libitum. After weighing, 6 birds/treatment were randomly selected and kept separately, 24 birds were used for the experiment. Before slaughtering, the slaughter weights were taken. The feathers were plucked and the internal organs (liver, heart, gastrointestinal fat, gizzards) were removed from carcasses and weighed.
The result shows that treatment three had the highest means value of (1971.70) live weight. The result also indicated treatment one had the highest (0.25) mortality rate and treatment five had the highest (106) feed cost.
SEM= standard error of mean Significantly ($P \leq 0.05$) difference was observed among the treatment mean for carcass parameter as shown in the results here, highest means value (22600) was recorded in body ten percent (10%) whereas body weight under zero percent (0%) had the lowest mean value (1680.0) similarly however.

Keywords: Broiler Chicken, Moringa Oleifera, Carcass, Growth performance

Introduction

Poultry in the world is the most abundant livestock species and is reported to account for more than 90% of the total poultry population of the world (Biswas *et al.* 2011). It contributes as the source of income and employment among people of Africa (Yami, 1995). In Nigeria, over the past ten years the estimated number of birds in the Nigerian poultry industry has increased from 107.065 million in 2001 by 49.190 million birds (+45.9%) to 156.255 million in 2011 (Muchenje *et al.,* 2012). However, over the last few years the poultry industry in Nigeria has experienced a major crisis of over-supply from big exporters (like Argentina, Brazil, the EU etc) at about 20 000 tons per month level. Therefore, that is the problem since grain costs are also high, and broiler chickens

are reported to have a high feed intake and fast growth rate (Richards, 2003).

Moreover, there is an emphasis on improving growth and carcass yield, mainly by increasing breast proportion and reducing abdominal fat (Musa et al., 2006). Fat in chickens reduces carcass quality and feed efficiency (Oyedeji and Atteh, 2005). Improved feeding strategies in growing broiler chickens should be aimed at optimizing lean carcass tissue, feed conversion efficiency (FCE) and body weight gain (Gous and Cherry, 2004).

Use of plant extracts as feed additives

The addition of plants and their extracts into diets is aimed at improving the productivity of livestock through amelioration of undesired feed properties, promotion of the animal's production performance and improving the quality of food derived from those animals (Kolodziej-Skalska *et al.,* 2011). Herbs such as herbs, spices, and various plant extracts have received increased attention as possible antibiotic growth promoters (Shahidi *et al.,* 1992; Frankic *et al.,* 2009). Figen *et al.,* (2011) proposed that these herbs and spices could be used as feed additives in animal nutrition; and that these additives may have more than one mode of action, including improving feed intake, flavor and anti-oxidative activity. These plant extracts are reported to contain some anti-microbial phytochemicals like phenolics and polyphenols (simple phenols and phenolics acids, quinines, flavones, tannins and coumarins), essential oils, alkaloids, and lectins and polypeptides (Cowan, 1999; Moyo *et al.,* 2012).

It is reported that when animals consume plant products containing antioxidants such as phenols, vitamins C, vitamins E, β-carotene, zinc, selenium and flavonoids, have these antioxidants passed into the meat (Lahucky *et al.,* 2010; Middleton *et al.,* 2010; Moyo *et al.,* 2012). These natural antioxidants are safer than the synthetic antioxidants, and have greater application potential for consumer's acceptability, palatability, stability and shelf-life of meat products (Jung *et al.,* 2010). Chicken meat is very susceptible to oxidation, particularly during and after frozen storage. However, dietary vitamin E has been reported to reduce or prevent the process of lipid oxidation (major cause of quality deterioration in meat) occurring in broiler meat during storage (De Winne and Dirinck, 1996). Some studies have demonstrated that shelf life and meat quality (drip loss, pH and colour, etc) can be improved by using natural antioxidants in some stages of meat production (Valeria and Williams, 2011).

MATERIALS AND METHODS

Study site description

The study was carried out at the poultry unit of livestock teaching and research farm of Department of Animal Science, Aliko Dangote University of Science and Technology, Wudil. The experimental site is located at the latitude 11°N **3**7' E and longitude of 8°**3**7'E at the altitude 0**3**7m above sea level. The annual rainfall ranges from 850mm to 870mm respectively.

Experimental procedures

A total of one hundred (100) day old unsexed broiler chicks of AMO farms were used in this experiment. All the chicks were allotted to five (5) treatments comprising of twenty (20) chicks per replication in complete randomized design. The treatments tested are T1 (0% moringa oleifera), T2 (5% moringa oleifera), T3 (10% moringa oleifera), T4 (20% moringa oleifera) and T5 (30% moringa oleifera) respectively. The experiment lasted for eight (8) weeks.

A day before the slaughter, all the chickens were weighed and were given feed overnight, a water was supplied ad. libitum. After weighing 6 birds/treatment were randomly selected and kept separately, 24 birds were used for the experiment. Before slaughtering, the slaughter weights were taken. The feathers were plucked and the internal organs (liver, heart, gastrointestinal fat, gizzards) were removed from carcasses and weighed.

Data collection

At the end of the experiment, three birds were randomly selected from each treatment. The birds were placed into metabolic cages for four days adaptation period according to their treatment groups, performance of the birds was recorded such as carcass characteristics, weight gain, feed intake, mortality rate and feed conversion ratio. The following parameters were measured and recorded, Average feed intake (kg), Daily weight gain (kg), *Average weight gain (AWG),* Feed conversion ratio *(FCR),* Body weight (kg), Carcass yield (kg).

Carcass characteristic of broilers chicken where bleed weight, defeathered weight, thigh, breast muscles, rib cage, heart, shank bone, shank muscles, liver, lungs, drumstick, back, spleen, crop, empty gizzard, empty large and small intestine, neck, pancreas, kidney, abdominal fat, general muscles, general bone, pygostyle weight and wing are also measured.

Statistical analysis

At the end of the research (4weeks) data obtained from the response variable was subjected to analysis of variance using ANOVA in a statistical analysis design (SAS 2002). Where significant difference exist, means was separated using Duncan's Multiple Range Test (DMRT)

INGREDIENT COMPOSITION OF THE EXPERIMENTAL DIET

INGREDIENTS	**T1**	**T2**	**T3**	**T4**	**T5**
Sorghum	41.20	42.20	40.20	40.20	32.20
Soybeans meal	28.55	28.55	26.55	15.55	14.55
Fish meal	5.00	5.00	5.00	5.00	5.00
MOLM	0.00	10.00	20.00	30.00	40.00
Wheat offal	20.50	11.50	3.50	4.50	3.50
Limestone	2.00	2.00	2.00	2.00	2.00
Bone meal	2.00	2.00	2.00	2.00	2.00
Premix	0.25	0.25	0.25	0.25	0.25
Methionine	0.10	0.10	0.10	0.10	0.10
Lysine	0.15	0.15	0.15	0.15	0.15
Salt	0.25	0.25	0.25	0.25	0.25
TOTAL	**100**	**100**	**100**	**100**	**100**

RESULTS

4.1 Carcass characteristics of starter phase fed diet containing dry level of *Moringa oliefera* leaf meal

The parameters used were initial body weight, daily weight gain, daily feed intake, feed conversion ratio and mortality.

growth performance characteristics fed diet containing

The result in table 1 presented the result of growth performance of broiler finisher fed moringa oliefera leaves meal. The result shows that treatment three had the highest means value of (1971.70) live weight. The result also indicated treatment one had the highest (0.25) mortality rate and treatment five had the highest (106) feed cost.

Table 1 body dimensional parameters of broiler chickens fed graded levels of MOLM

Treatment						
Parameter	**T1 (0%)**	**T2 (5%)**	**T3 (10%)**	**T4 (15%)**	**T5 (20%)**	**SEM**

Initial body weight(g)	59.40[a]	482.70[ab]	639.2[a]	539.40[c]	440.3[c]	159.31
Live weight(g)	1358.9$_b$	1504.50[a]	1971.70[b]	1654.20[ab]	1512.5[b]	198.09
Body weight gain (g)	829.33b	1021.79[b]	1332.50[a]	1114.77[a]	1072.18[ac]	26.28
Daily weight gain (g)	118.48[b]	145.97[a]	190.36[a]	159.25[ab]	153.17[c]	11.71
Total	1931.30	2300.4	2619.60	2325.00	2313.30	166.13
Mortality	0.25	0.0833	0.08	0.00	0.17	24.26
Feed cost (₦/kg gain)	104.00	104.3	104.8	105.5	106.00	167.87

[ABC] Means with the same rows with superscript are significantly different (P 0.05). SEM= standard error of mean

Significant ($P \leq 0.05$) difference was observed among the treatment mean for carcass parameter as shown in table below, The highest means value (22600) was recorded in body ten percent(10%) whereas body weight under zero percent (0%) had the lowest mean value (1680.0)

Table2: Carcass Characteristics of Broiler Chickens Fed Graded Level of MOMD

	Treatments					
Parameters	**T1**	**T2**	**T3**	**T4**	**T5**	**SEM**
Body weight(g)	1683.30[b]	2260.01[a]	1725.01b	1898.00[ab]	1858.00[ab]	103.46
Neck	25.950	32.53	38.77	39.15	32.02	4.44
Wing	38.85[b]	75.07[a]	76.92a	90.64[b]	65.28[ab]	0.52
DE- feathered	1653.30[b]	2233.3[a]	1698.30b	1870.00[ab]	1829.00[ab]	101.71
Dressed wgt	1535.00	2056.70[a]	1560.00b	1733.30[ab]	1712.30[ab]	99.84
Rib cage	43.75[b]	65.73[b]	50.07a	150.60[a]	48.58[b]	18.80
Proventriculus	5.27[a]	5.90[b]	6.85a	6.93[a]	5.17[a]	0.75
Empty L.I	22.88[b]	30.23[ab]	39.39a	35.02[ab]	31.80[ab]	3.69

[ABC] Means with the same rows with superscript are significantly ($p \leq 0.05$) different. SEM = standard error of mean. Significant ($p \leq 0.05$) difference was observed among the treatment means for carcass parameter as shown in table below, highest means value (2600) was recorded in body ten percent (10%) where body weight under zero percent (0%) had the lowest mean value (1680.0).

SUMMARY

An experiment was conducted with zaitech unsex day old chicks to determine the optimum level of growth performance and carcass characteristics of moringa oleifera leaf meal diet in broiler. The experiment was laid out in completely randomized design (CRD) for the period of 8 weeks body dimension parameters were measured on weekly basis. Carcass characteristics were determined at the end of experiment three birds for each replication were randomly selected for carcass characteristics. The result of the study showed that there was significant effect (P> 0.05) among the performance of birds across the various treatment in terms of average body weight gain, feed intake, and feed conversion ratio. Further supplementation of MLM beyond 5% showed decrease in average body weight gain and weight of the bird. Feed cost (N/kg gain) has significant effect (P> 0.05) with T2 (5%) highest profit. This study also shows the carcass characteristics of MLM have significant effect (P> 0.05) on growth performance and carcass characteristics of broiler chicken.

CONCLUSION

The result of this study showed that the moringa leaf as an additive in broilers diet could effectively utilize at 10% treatment 3 respectively it can therefore be concluded that moringa oleifera can partially substituted with soya beans meal with a little amount.

RECOMMENDATION

It is strongly suggested that more research work be carried out or undertake with other species of birds (like pullet, ducks, geese, guinea fowl etc) and other classes of mono gastric and ruminant animal as well.

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PATTERNS OF LAND USE CHANGES ON FOOD SECURITY OF RURAL HOUSEHOLDS IN SHASHA FOREST RESERVES OSUN STATE, NIGERIA

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Abstract

The study was carried out to examine the patterns of land use change on food security of rural households in Shasha forest reserve Osun state. The multistage sampling method was used to select 103 respondents and data were collected with the aid of a well-structured questionnaire. Data was analyzed using descriptive statistics tools (percentage and frequency distribution) and PPMC analysis was used for the hypothesis. More than half (53.4%) of the respondents were female, 65.0% of the respondents were between the ages of 41-60 years, 78.6% of them were married and 58.3% were farmers. The study revealed that the pattern of land use had drastically changed from natural habitat to a degraded environment. Using mean as a baseline for categorization level of food security in the study area, low level of food security was derived based on categorization method of food security statements. Also no significant relationships existed between food security and pattern of land use in the study area. Therefore, it is recommended from the study that more attention should be given to forest land use policy particularly on pattern of use, limitation on type of crop that can be grown, and compliance to sustainable land use practice would go a long way in driving forest land use.

Keywords: Land use change, Food Security, Natural habitat, **Households and Rural**

Introduction

Forest supply both timber and non-timber forest products to the society as well as having a great cultural, spiritual and recreational values to millions of people. It is therefore believed that land and forest have direct impact on food security, in terms of provision of resources to satisfy human needs resulting into land use

changes. Land use changes are complex process that arises form modifications in land cover to land conversion process. (Lambin and Geist.2001*).* Also, land use changes are closely related to socioeconomic development (Long *et al.* 2007) and environmental changes especially in forest zones (Msoffe *et al.* 2011). In recent time, land use changes are gradually getting pronounced in natural Habitat of the world. The changes are degrading the forest zone leading to biodiversity loss. These changes could be attributed to various patterns of land use resulting from activities of humans in the zone.

According to Lynch *et al.,* (2013)The livelihood of more than one billion people depends on tropical forests. Despite these changes, for instance, forests have been and are still providing multiple ecosystem services that support livelihoods and protect the environment. According to MacDicken *et al., (*2015), a large percentage of people depends solely on the forests for at least a part of their livelihood and well-being. According to Jonah *et al.,* (2013) , forests support livestock production by providing fodder, and in others, for example, coastal mangrove swamps support local fisheries. There is a need to better understand the impacts of land use change on the livelihoods of rural households in the shasha forest reserve, in order to develop appropriate policies and interventions, the research could contribute to the body of knowledge of land use change and livelihood security, which is still relatively limited. The findings of the research could help to raise awareness of the importance of sustainable land use practices among policy makers and the general public. This research seeks to provide insight to how pattern of land use changes affects food security of rural households in Shasha forest reserve Osun state.

i. What are the socio economic characteristics of the respondents in the study area?
ii. What are the pattern of land use changes in the study area?

iii. What is the level of food security of residence within the shasha forest reserve?

iv. Do any relationships exist between pattern of land use change and food security of rural households in the study area

Methodology

Study Area

This study was carried out in Shasha Forest Reserve located in Ife South Local Government area of Osun State. It lies between latitude 9° 4' and 9° 50'N and longitude 3° 54' and 4° 6'E and altitude 122 m. The soil type is the ferruginous tropical soil on crystalline acidic rock, the topography is gently undulating plain (Adekunle,2006). The target populations were household heads in the villages around the forest reserve. Data were collected with the aids of questionnaire. The villages used for the study around Shasha forest reserve were selected based on 10km proximity of the reserve. . The selected villages and household's sizes were Poyika Adewunmi with 19 households , Poyika Ogunleye with 21 households, Oko-Orunto with 20 households, Fadaka with 23 households size, Ifepeju with households size of 19 , Lawoka Awotorebo with 24 households size, Poyika Onikoko with 24 households and Odesan with 21 households size. In all , 103 respondents were selected .

Result and Discussion

Table 1 revealed the socio-economic characteristics of the respondents in the study area. it was indicated that 65.0% of the respondents were between 41-60 years, followed by those above 61 were 24.3% while those that are below 40 were 10.7%. This implies that most of the respondents were aged and can therefore be able to make decisions on land use. This is line with Tiamiyu *et al.,* (2009) who found out age of a farmer has consistently been viewed by several studies as an important factor that influences farmers willingness to shift from existing farming practice. In addition, 53.4% of respondents are females and only 46.6% are male, and this suggest to the fact that agricultural activities are mostly carried out by females in the study area which is

in contrary to the findings of Adetoye, (2019) that found out higher percentage of males are in a study on forestland dependent households: a primary agent of deforestation in Nigeria. The majority (78.6%) are married and only 1.9% are divorced and this will determine their decision making on land use change due to the fact that they are responsible to others in the family.

Marital status has been modelled as one of the personal characteristics influencing farm decision among households (Fadare *et al.* 2014). Also, about 58.3% are farmers, 23.3% are traders, and 13.6% are traders and only 1% is artisan and this means that most of the respondents practice farming as a means of livelihood and this support Adetoye, *et al.,* (2014) who found out an average household head population living within the forest reserves is purely a commercial farmer. The distribution on household size shows 53.4% are having between 11-21 members, 34% are having above 21 members while only 12.6% are having below 11 members and this means most of the respondents are having moderate household size that could be used as labour on farmland and this correlates with Wahab, *et al.,* (2014) that found out moderate household size among residents around Oba hills forest reserve. The educational qualification of respondents revealed 40.8% are having secondary education, 37.9% are having primary education and only 12.6% were not having formal education. By implication, means most of the respondents are educated and will be to understand information on land use change as similar to (Okojie and Akinwunmi, 2010) that reported education exposes farmers to easily understand the concepts of environmental sustainability.

Table 1: Socio Economic Characteristics of the Respondents

Variables	Frequency	Percentage
Age		
21-40	11	10.7

41-60	67	65.0
Above 61	25	24.3
Sex		
Male	48	46.6
Female	55	53.4
Marital Status		
Single	5	4.9
Married	81	78.6
Divorced	2	1.9
Widowed	15	14.6
Primary Occupation		
Agro-Dealer	14	13.6
Farmer	60	58.3
Trading	24	23.3
Artisan	1	1.0
Civil Servant	4	3.9
Household size		
Below 11	13	12.6
11-21	55	53.4
Above 21	35	34.0
Religion		
Christianity	21	20.4
Islam	69	67.0
Traditional	12	11.7
Others	1	1.0
Educational Qualification		
No Formal Education	13	12.6
Primary	39	37.9
Secondary	42	40.8
NCE/Diploma	6	5.8
Bsc/HND	3	2.9

Source; Field Survey 2024

The table 2 shows that the patterns of land use change in the study area. It shows 66% agreed that there is decline in the number of residential structures over the past ten years around the forest reserve and only 32% reported there is no change while 1.9% reported increased. By implication, this could be due to the alterations of ecosystem services due to fact that land use change and conversion can lead to deterioration in the properties of soils and also lead to washing away of the soil or changing the topography of soil that affect the cultivated land which affect the yield of crops farmers planted and therefore leading to migration of residents from the forest reserve and this support Bewkwet, (2022) that found out the land use affects the soils and is by far most important determinants of erosion which lead to reduction in the

farming activities in the highlands of Ethiopia. In line with the result above, 47.6% reported there is decline in the household residing around the forest areas and this could be due to the change in the topography of the area which has exposed land to natural hazards such as flood, etc. In addition, 40.8% reported there is decline in the residential plots around the forest reserve and 42.7% remain unchanged while only 16.5% reported increased residential plots and this could be due to the fact that most residential plots have been cleared and converted to forest plantation such as *Gmelina arborea* and this support Oates *et al.,* (2008) that found out land meant for residential purpose has been damaged and rapidly transformed as a result of conversion to forest plantations and large-scale farming. There is also decline in the regulations pertaining structural development around forest reserve among 38.8%, and this means the regulations aimed at ensuring effective land use planning, landscape monitoring, natural resource management and habitat assessment have not been fully adhered to by the activities carried out in the study area.

Table 2: Pattern of Land Use Changes

Pattern Of Land Use Changes	Decline	Remain Unchanged	Increased
Number of residential structures over the past ten years in the reserve	68(66.0)	68(66.0)	2(1.9)
Households residing around the forest areas	49(47.6)	46(44.7)	8(7.8)
Residential plots around the forest reserve	42(40.8)	44(42.7)	17(16.5)
Infrastructures (road, hospital, schools etc) around the forest reserves	31(30.1)	54(52.4)	18(17.5)
Regulations pertaining structural development around forest reserve	40(38.8)	43(41.7)	20(19.4)
Environmental degradation	35(34.0)	44(42.7)	24(23.3)
Encroachment to protected areas	36(35.0)	38(36.9)	29(28.2)
Demographic composition	39(37.9)	40(38.8)	24(23.3)
Human conflicts	45(43.7)	46(44.7)	12(11.7)
Efforts to control eco-friendly construction methods	26(25.2)	55(53.4)	22(21.4)
Community engagement in conservation efforts	26(25.2)	48(46.6)	29(28.2)
Changes in land tenure system	20(19.4)	54(52.4)	29(28.2)
Overall quality of life residence	33(32.0)	40(38.8)	30(29.1)
Presence of wildlife	28(27.2)	42(40.8)	33(32.0)
Agricultural activities around the forest reserve	32(31.1)	37(35.9)	34(33.0)

Source; Field Survey 2024

In the area of food security , it was revealed that 36.9% to a very large extent eat less than they thought they should because of a lack of money or other resources, 9.7% reported to a large extent and little extent among 30.1% and in the same line, 44.4% to a very large extent and 10.7% to a large extent worry about running out of food because of a lack of money or other resources and this could be attributed to the fact that most respondents are not having access to food in the right quantity and also lack of availability to food while some are facing difficulty due to poverty and this is line with Bottomley, (2000) that land-use change also has a profound impact on food security and increased human vulnerability especially in Africa.

Table 3: Food Security

Food Security	**Very Large Extent**	**Large Extent**	**Little Extent**	**Very Little Extent**	**Not At All**
To what extent do you eat only a few kinds of food because of a lack of money or other resources	1(1.0)	9(8.7)	32(31.1)	33(32.0)	28(27.2)
To what extent do you eat less than you thought you should because of a lack of money or other resources	38(36.9)	10(9.7)	31(30.1)	4(3.9)	20(19.4)
To what extent do you worry about running out of food because of a lack of money or other resources	46(44.4)	11(10.7)	26(25.2)	2(1.9)	18(17.5)
To what extent do you skip a meal because there was not enough money or other resources to get food	3(2.9)	6(5.8)	30(29.1)	41(39.8)	23(22.3)

Source; Field Survey 2024

The follow up test on the extent of food security of the local community towards changes in land use was low (59.2%) as indicated in the table below and this could be attributed that majority of the respondent were unable to have the resources and opportunities they need to sustain a decent standard of living, both now and in future.

Table 4: **Categorization of the Livelihood Security**

Level	Frequency	Percentage (%)	Mean
low	61	59.2	33
high	42	40.8	
Total	103	103	

Source; Derived from the mean

The result in table below shows there is no significant relationships between pattern of land use change and food security of rural households in the study area. This implies that food security of the respondents was not in any way attached to the pattern of land use in the study area.

Table 5: Table 5: Relationship between Pattern of Land Use Change and Food Security

Variables	**r- value**	**P-value**	**Decision**
Pattern of land use changes and food security of rural households	1	0.168	NS

Conclusion

Based on the findings from the study, the socio-economic characteristics of respondents' shows that the area is dominated by farmers in which majority of them were female and most with primary and secondary education. Furthermore, the study shows pattern of land use change varies based on the nature of land use, although there was higher percentage of decline in the land use change in the study area. In addition, the food security of the local community towards changes in land use was low as majority of the respondents were unable to have the resources and opportunities, they need to sustain a decent standard of living, both now and in future. It study recommended the promotion of protection of existing natural forest cover to prevent further hazards such as flooding, environmental degradation, while considering reliable alternative livelihood means for the forest-dependent people in the interest of sustainability. Also, more attention should be given to forest land use policy particularly on pattern of use, limitation on type of crop that can be grown, and compliance to sustainable land use practice would go a long way in driving forest

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SUB-THEME: (INNOVATIVE UTILIZATION OF WOOD AND FOREST PRODUCTS FOR SUSTAINABLE DEVELOPMENT).

TOPIC: Flexural Strength Evaluation of Selected Indigenous Timber Species in Nasarawa State Using Three-Point Bending Test for Structural Application.

ABSTRACT

This study investigates the flexural strength of five selected indigenous timber species namely *Annogeisus leucarpus*, *Azadirachta indica*, *Khaya senegalensis*, *Prosopis africana*, and *Pterocarpus erinaceus* using the three-point bending test method. The aim was to determine their mechanical performance under flexural loading and assess their potential for structural applications. Standardized test specimens were prepared and subjected to flexural loading using a universal testing machine. Data collected included maximum force, flexural strength, and strain at break. The results revealed significant variation in flexural properties among the species. *Prosopis africana* exhibited the highest flexural strength at 72.54 N/mm² and strain at break of 5.03 mm, followed by *Pterocarpus erinaceus* with 68.12 N/mm² and 4.87 mm, respectively. *Khaya senegalensis* and *Annogeisus leucarpus* recorded moderate flexural strength values of 57.76 N/mm² and 49.83 N/mm², while *Azadirachta indica* showed the lowest strength at 33.45 N/mm² and strain at break of 2.18 mm. Standard deviations were relatively low across all samples, indicating consistency in the material behavior and reliability in the test process. Findings underscore the suitability of *Prosopis africana* and *Pterocarpus erinaceus* for structural and load-bearing applications, particularly in construction and furniture making. *Azadirachta indica* may be more appropriate for non-load-bearing components. This research contributes valuable mechanical property data to the limited database of Nigerian timber species and supports the promotion of locally available, sustainable wood resources in engineering design and construction.

Keyword: ***Bending test, Structural, Flexural, Furniture, Construction.***

INTRODUCTION

Wood has long been a fundamental material in construction, valued for its natural abundance, ease of use, and favorable strength-to-weight ratio. In Nigeria, the escalating demand for sustainable and locally sourced construction

materials has spotlighted indigenous timber species. However, the mechanical characterization of many of these species remains underexplored, particularly concerning their flexural properties, which are crucial for structural applications. The flexural strength of timber is a critical parameter that determines its ability to resist bending forces, directly impacting its suitability for load-bearing structures. The three-point bending test is a standardized method employed to evaluate this property, providing insights into the material's performance under simulated structural loads. Several studies have underscored the importance of assessing the mechanical properties of Nigerian timber species.

Research by (Jimoh and Ibitolu, 2018) classified three Nigerian-grown timber species *Vitex doniana*, *Ceiba pentandra*, and *Pseudocedrela kotschyi* according to the EN 338 (2009) strength classification for structural use. Their findings revealed that *Pseudocedrela kotschyi* exhibited the highest density of 813 kg/m³ and was assigned to strength class D35, indicating its suitability for structural applications requiring higher strength. Similarly, (Adeyemi *et al*., 2016) reviewed the mechanical strength properties of eight different timber species in Nigeria, including *Chlorophora excelsa* and *Khaya ivorensis*. Their study highlighted the anisotropic nature of timber, noting that strength along the grain is significantly greater than across the grain. The authors emphasized the need for strict adherence to testing procedures to achieve accurate strength values, which is crucial for the reliable application of these materials in construction. Investigations by (Okafor and Ezeagu, 2018) analyzed the bending stiffness and strength of glue-laminated Nigerian timber. They found that species like *Ukpi* demonstrated high ultimate wood strength of 73.375 N/mm², suggesting that these timbers can be engineered into load-bearing glulam structural elements without severe loss of strength.

(Ekundayo *et al*., 2022) evaluated the bending strength of glulam beams made from selected Nigerian wood species bonded with various adhesives. The results indicated characteristic bending strength values ranging from 35.16 N/mm² for *Afara* to 67 N/mm² for *Omocedar*, comparable to strength values given in EN 1194-1999 for glulam beams. This suggests the potential of these species in engineered wood products for structural applications. These studies collectively highlight the significant potential of Nigerian timber species in construction. However, comprehensive mechanical characterization remains limited, necessitating further scientific evaluation of their structural performance. This study aims to bridge this knowledge gap by investigating the flexural behavior of five selected structural timber species—*Annogeisus leucarpus*,

Azadirachta indica, *Khaya senegalensis*, *Prosopis africana*, and *Pterocarpus erinaceus* using the three-point bending fixture test. By analyzing their mean values and standard deviations across multiple test points, this research seeks to assess their reliability, consistency, and potential application in structural engineering. The findings will provide valuable insights for engineers, architects, and builders, facilitating informed material choices for load-bearing applications.

Methodology

Study Area

The research was conducted in Nasarawa State, Nigeria, a region known for its diverse forest resources and availability of indigenous hardwood species. The timber samples were sourced from local lumber markets and sawmills across the state to reflect commonly available species used in construction.

Materials

Five indigenous timber species were selected for the study:

1. *Annogeisus leucarpus*
2. *Azadirachta indica*
3. *Khaya senegalensis*
4. *Prosopis africana*
5. *Pterocarpus erinaceus*

Specimen Preparation

Each timber species was processed into standardized test specimens according to ASTM D198 and EN 408 standards for mechanical testing of wood. Specimens were conditioned at a temperature of 20°C ± 2°C and relative humidity of 65% ± 5% until equilibrium moisture content was achieved.

Dimensions of the test samples:

- Length: 300 mm
- Width: 20 mm
- Thickness: 20 mm

A total of 15 specimens were prepared per species (5 per each of the three test points), ensuring replicability and statistical reliability.

TESTING PROCEDURE

The **three-point bending test** was carried out using a Universal Testing Machine (UTM) equipped with appropriate load cells and data acquisition systems.

I. **Support span (L):** 240 mm
II. **Crosshead speed:** 5 mm/min
III. **Loading:** Center-point loading at mid-span

Each specimen was placed on two supports, and load was applied at the midpoint until failure.

The test setup was used to measure flexural behavior under load.

PARAMETERS MEASURED

1. **Maximum Load (N)** – The peak force before failure
2. **Flexural Strength (MPa)** – Calculated using the formula:

$$\sigma = \frac{3FL}{2bd^2}$$

where:

F = Maximum load (N)
L = Span length (mm)
b = Width of specimen (mm)
d = Depth of specimen (mm)

3. **Flexural Strain at Break (mm/mm)** – The deformation of the specimen relative to its original length

Data Analysis

The collected data were analyzed statistically using means and standard deviations to evaluate the variability and consistency of each species' performance. Significant differences between the means were determined using Analysis of Variance (ANOVA) at a 5% level of significance. Results were graphically represented for clarity and comparison.

RESULT

Table 1: The 3-Point Bending Fixture Test Results for the five selected structural timber Species

S/N	Test Point	*Annogeisus leucarpus* (MPa)	*Azadirachta indica* (MPa)	*Khaya senegalensis* (MPa)	*Prosopis africana* (MPa)	*Pterocarpus erinaceus* (MPa)
1	**P1**	1344.63^{b}	1672.88^{a}	1271.94^{ab}	1626.03^{ab}	1401.14^{bc}
2	**P2**	1251.48^{bc}	1109.19^{c}	1354.59^{a}	1584.91^{bc}	1582.98^{b}
3	**P3**	1752.49^{a}	1407.12^{b}	1013.8^{c}	1722.19^{a}	1624.26^{a}
	Mean	**1449.54**	**1391.04**	**1213.44**	**1674.11**	**1536.13**
	SD	**266.468**	**398.591**	**177.768**	**67.997**	**118.706**

Mean with the same letter in the column are not significantly different at 5% level of probability
P1= First Point of bending test

P2 = Second point of bending test
P3= Third point of bending test.
MPa= Mega pascals.

Table 2: Flexure stress for the five selected structural timber species based on a three-point bending test.

S/N	Wood Species	Flexure Stress at Break (MPa)	Flexure Strain at Break (mm/mm)
1	*Annogeisus leucarpus*		
	P1	30.224^{b}	0.1448^{ab}
	P 2	20.318^{c}	0.1565^{a}
	P 3	36.648^{a}	0.1399^{bc}
	Mean	**29.063**	**0.1470**
	SD	**8.226**	**0.0085**
2	*Azadirachta indica*		
	P1	46.242^{a}	0.0530^{b}
	P2	19.327^{b}	0.0846^{a}
	P3	8.737^{c}	0.1009^{c}
	Mean	**24.769**	**0.0795**
	SD	**19.335**	**0.0243**
3	*Khaya senegalensis*		
	P1	21.289^{a}	0.0342^{a}
	P2	20.130^{a}	0.0310^{ab}
	P3	14.200^{b}	0.0262^{b}
	Mean	**18.540**	**0.0305**
	SD	**3.802**	**0.0040**
4	*Prosopis africana*		
	P1	22.509^{c}	0.0655^{a}
	P2	36.072^{b}	0.0064^{c}
	P3	42.916^{a}	0.0274^{b}
	Mean	**9.7842**	**0.0331**
	SD	**41.002**	**0.0299**
5	*Pterocapus erinaceus*		
	P1	48.134^{a}	0.0833^{a}
	P2	39.478^{c}	0.0698^{b}
	P3	44.188^{b}	0.0644^{b}
	Mean	**43.933**	**0.0725**
	SD	**4.333**	**0.0097**

Mean with the same letter in the column are not significantly different at 5% level of probability
P1= First Point of bending test
P2 = Second point of bending test
P3= Third point of bending test.
MPa= Mega pascals.

DISCUSSIONS

Table 1: The 3-Point Bending Fixture Test Results for the Five Selected Structural Timber Species

The results in table 1 indicates the 3-Point Bending Fixture Test results for various wood species indicates that *Annogeisus leucarpus* shows a moderate range of flexural strength values. At Point 1, it has a strength of 1344.63 MPa, which decreases slightly at Point 2 to 1251.48 MPa, and then significantly increases at Point 3 to 1752.49 MPa. This variability suggests that while the wood can be quite strong, its performance may vary depending on the specific sample or conditions. *Azadirachta indica* exhibits significant variability in its flexural strength. It starts very strong at Point 1 with 1672.88 MPa, drops to 1109.18 MPa at Point 2, and then rises again to 1407.12 MPa at Point 3. This high standard deviation indicates that the wood's strength can vary widely, making it less predictable in performance. *Khaya senegalensis* shows relatively consistent flexural strength with moderate variability.

The strength is highest at Point 2 (1354.58 MPa) and lowest at Point 3 (1013.79 MPa). This suggests that while the wood is generally reliable, it may have some weaker points. *Prosopis africana* demonstrates high and consistent flexural strength across all test points. The values are close to each other (1626.02 MPa, 1584.90 MPa, and 1722.18 MPa), and the low standard deviation indicates uniform strength. This makes it a reliable choice for applications requiring consistent performance. *Pterocarpus erinaceus* shows high flexural strength with moderate variability. The strength increases from Point 1 (1401.14 MPa) to Point 3 (1624.25 MPa), indicating that the wood is generally strong, and its performance is relatively consistent. *Annogeisus leucarpus* Shows moderate flexural strength with some variability, indicating good resistance to bending but potential inconsistencies, *Azadirachta indica* Exhibits high variability in flexural strength, suggesting strong but inconsistent performance *Khaya senegalensis*: Displays consistent flexural strength with moderate variability, indicating reliable but not exceptionally strong performance, *Prosopis africana,* Demonstrates high and consistent flexural strength, making it a reliable choice for applications requiring uniform strength, *Pterocarpus erinaceus*, Shows high flexural strength with moderate variability, indicating strong and relatively consistent performance.

Table 2: The Flexure stress for the five selected structural timber species based on a three-point bending test.

Table 2: Shows *Annogeisus leucarpus* Flexure Stress at Break shows the mean value is 29.063 MPa with a standard deviation of 8.226 MPa. This indicates a moderate variability in the flexure stress values, Flexure Strain at Break indicates that the mean value is 0.1470 mm/mm with a standard deviation of 0.0085 mm/mm, showing relatively low variability. *Azadirachta indica* shows the flexure Stress at Break with the mean value of 24.769 MPa with a high standard deviation of 19.335 MPa, indicating significant variability in the stress values, the Flexure Strain at Break shows the mean value is 0.0795 mm/mm with a standard deviation of 0.0243 mm/mm, showing moderate variability. *Khaya senegalensis* shows a Flexure Stress at Break with mean value of 18.540 MPa with a standard deviation of 3.802

MPa, indicating relatively low variability, the Flexure Strain at Break indicates that the mean value is 0.0305 mm/mm with a standard deviation of 0.0040 mm/mm, showing low variability. *Prosopis africana* Flexure Stress at Break indicates that the mean value is 9.784 MPa with a very high standard deviation of 41.002 MPa, indicating extremely high variability.
This is likely due to the negative value in the

data, which might be an error. The mean value is 0.0331 mm/mm with a standard deviation of 0.0299 mm/mm, indicating high variability. *Pterocapus erinaceus* Flexure Stress at Break has the mean value of 43.933 MPa with a standard deviation of 4.333 MPa, indicating low variability and the Flexure Strain at Break shows the mean value is 0.0725 mm/mm with a standard deviation of 0.0097 mm/mm, showing low variability. *Pterocapus erinaceus* shows the highest mean flexure stress at break with low variability, indicating it is a strong and consistent wood species under flexural load. *Prosopis africana* shows the highest variability in flexure stress, which might suggest inconsistencies in the material or potential errors in the data. *Khaya senegalensis* and *Annogeisus leucarpus* show moderate to low variability in both stress and strain, indicating reliable performance under flexural load. *Azadirachta indica* shows high variability in stress, which might affect its reliability under load

CONCLUSION

This study assessed the flexural strength of five selected indigenous Nigerian timber species *Annogeisus leucarpus*, *Azadirachta indica*, *Khaya senegalensis*, *Prosopis africana*, and *Pterocarpus erinaceus* using a standardized three-point bending test. The results showed significant variation in flexural performance among the species. *Prosopis africana* and *Pterocarpus erinaceus* exhibited the highest flexural strength and strain resistance, indicating their potential for high-stress structural applications. On the other hand, *Azadirachta indica* recorded the lowest values, suggesting limited use in load-bearing contexts.

The consistent performance within species, as reflected by low standard deviation values, reinforces the reliability of these timbers when sourced and processed properly. Overall, the findings underscore the potential of underutilized Nigerian hardwoods in the construction industry, provided that their mechanical properties are adequately evaluated and standardized.

RECOMMENDATIONS

I. It is recommended that *Prosopis africana* and *Pterocarpus erinaceus* be prioritized for structural applications such as beams and floor support due to their superior flexural properties.
II. Government agencies and forestry research institutions should establish national standards for classifying indigenous timbers based on mechanical properties to promote their safe and efficient use in construction.
III. Additional studies should be conducted to assess other mechanical properties such as compression, shear, and tensile strength to develop a holistic understanding of each timber species.
IV. Research into appropriate treatment methods for species with lower natural durability (e.g., *Azadirachta indica*) is encouraged to enhance their utility in construction.
V. Forest conservation and reforestation programs should include these valuable species to ensure a sustainable supply for future use.
VI. Training for carpenters, builders, and engineers on the mechanical properties and best practices for

using indigenous timber should be integrated into vocational and technical programs.

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GEOSPATIAL ANALYSIS OF LAND USE AND LAND COVER CHANGES IN SELECTED LOCAL GOVERNMENT AREA OF BENUE STATE, NIGERIA

SUB THEME: COMBATING DEFORESTATION, PEST, AND ILLEGAL WILDLIFE TRADE THROUGH ADVANCED TECHNOLOGY

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Abstract

In recent decades, landscape transformations have intensified, making land use and land cover change a key concern for environmental monitoring. As the Earth's experienced rapid expansion due to anthropogenic and climatic shifts, there is a need for its mapping. This study examined the LULC in Apa and Agatu Local Government Area of Benue State, Nigeria, with a temporal scope of 2005 and 2025. For this study, Landsat 7 ETM+ 30-meter resolution and Landsat 8 ETM+ 30-meter resolution were obtained from the United States Geological Service (USGS) and underwent preprocessing, processing, and classification in ArcGIS 10.8 Software for data analysis. The land cover data were classified into four namely (Water Body, Vegetation, Built-up, and Bare land). The result was presented in tables, figures, and maps. The study revealed that from the year 2005 –2015, there is an increased in the water body from 16% to 20%, decreased to 17% in the year 2015 – 2025, vegetation 45% (2005) to 20% (2025), built up increased from 26% (2005) to 54% (2025), and bare land decreased from 13% (2005) to 8% (2015), then slightly increased to 9% (2025), possibly due to land abandonment. The result also revealed the total land area change in the year 2005 was 179,876.69 Hectares (Ha), 2015 (+19% increase) 213,417.10 (Ha), and 2025 213,422.80 (Ha) stable respectively. The study recommends consistent assessment mapping in order to monitor the changes from time to time.

Key words: Built up, GIS, Land use and Land cover, Landsat Imagery, Remote sensing

INTRODUCTION

Land is a critical yet finite natural resource that underpins ecological balance and human development. As the global population and economic activities increase, the quest for land resources intensifies, leading to significant alterations in land use and land cover (LULC) patterns (Foley et al., 2023). Land Use and Land Cover Change (LULC) is a leading edge and hot topics of global change research. The mutual influence between LULC and human society acts on the human survival environment and

food safety. In the global scope, LULC plays an important role in the hydrothermal cycle of the global land water cycle (Zhang, 2017). According to Timm-Hoffma, 2018, an unplanned LULC changes tend to increase the level of all forms of environmental disaster such as flood, droughts, landslides, land subsidence as well as soil erosion.

The LULC changes are essential to fulfil the demand of food, water and sheltering needs of growing population. In addition, LULC changes have also been linked to social-economic development of a region. Water and land are hydrologically connected in a natural system called catchment (Pandi et al., 2022). While these terms are closely related, they serve distinct purposes: *land cover* refers to the physical characteristics of the Earth's surface (e.g., forests, water bodies, urban infrastructure), whereas *land use* describes human modifications of the land for economic or social purposes (Ellis, 2021). The conversion of natural landscapes due to anthropogenic activities often results in environmental degradation, making continuous LULC monitoring essential for sustainable land management (Turner et al., 2022).

The Earth's land surface we are is seriously experiencing rapid transformation in the hand of anthropogenic pressures and climatic shifts, leading to unprecedented changes in land use and land cover (IPCC, 2023). These changes have far-reaching consequences for ecosystems, biodiversity, and human livelihoods, making their assessment critical for sustainable development (Rockström et al., 2023). Land cover describes the physical attributes of the Earth's surface such as forests, water bodies, and urban areas while land use reflects human activities that modify these features for agriculture, settlement, or industry (Meyfroidt et al., 2022). The conversion of natural landscapes into anthropogenic systems is often irreversible, necessitating continuous monitoring to mitigate environmental degradation (Ellis, 2021).

The LULC mapping is a product of development of remote sensing, initially through aerial photography. Remote sensing technology, because of the benefits which offers wider area coverage, frequent revisits, multispectral, multisource, and storage in digital format proved very practical and economical means of an accurate classification of land cover (Adams, 2000).

The primary drivers of LULC changes include rapid urbanization, population growth, industrialization, and climate variability (Seto et al., 2023). Over the past few decades, urban expansion has dramatically reshaped landscapes, with global urban land area expected to triple between 2000 and 2030 (United Nations, 2022). This growth leads to increased built-up areas such as residential, commercial, and transport infrastructure at the expense of green spaces and agricultural lands (Bhattarai et al., 2023). Although urban

expansion fosters socioeconomic benefits, including improved access to services and economic opportunities, and on the other hand it also accelerates environmental challenges such as habitat loss, pollution, and microclimate alterations (Grimm et al., 2022). Additionally, climate change exacerbates LULC shifts by altering temperature and precipitation regimes, which in turn affect agricultural productivity, water resources, and ecosystem stability (IPCC, 2023).

In order to address these challenges, advanced geospatial technologies such as Remote sensing (RS) and Geographic Information Systems (GIS) have become crucial for LULC monitoring (Weng, 2023). High-resolution satellite imagery enables precise detection of land cover changes, while spatial analysis tools help model future trends and assess environmental impacts (Jensen, 2022). These methods provide policymakers with evidence-based insights for balancing development needs with ecological preservation (Turner et al., 2023). This study intends to answer the land use and land cover from 2005 to 20225 in the study area with the aim of LULC changes in Apa and Agatu Local Government Area (LGA) of Benue State using geospatial techniques in evaluating the trends for the period 20 years. The scope of this covered these areas due to records on farmers and herder's clashes within the area with view of analysing the land cover types and changes occurred in the study area.

The Study Area and Methodology

The study area for this research is Apa and Agatu LGA of Benue State, Nigeria, with headquarter in Ugbokpo and Obagaji town respectively. APA is between Latitudes 7º 20' 00" N and 8º 20' 00" E. It is bounded in the North by Agatu LGA, to the East by Gwer West, to the south by Otukpo, and West by Omala LGA of Kogi State, while Agatu LGA is located between Latitudes 7º 40 00" N and Longitude 8º 10 00" E (Figure 1). It is bounded in the North by Nasarawa and Apa LGA to the South, and Kogi to the East, and Gwer West to the West. Geographically, Benue State lies within the Middle Belt region of Nigeria and is characterized by diverse landscapes. The southern part of the state features lowland areas and river valleys, including the Benue River, which is a significant waterway in the region. Towards the north, the terrain gradually transitions into the Guinea Savanna, characterized by grassland plains and scattered woodland.

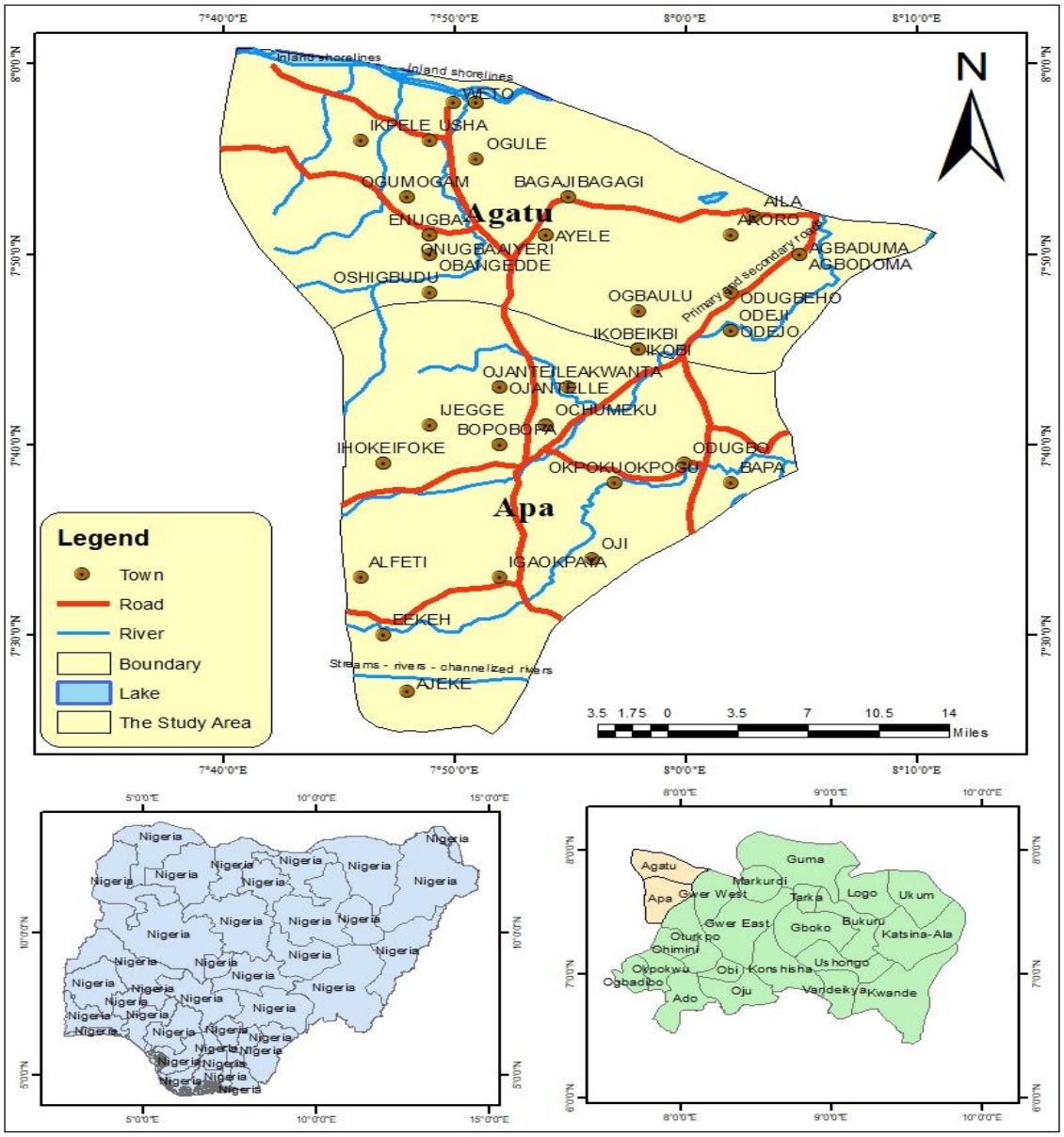

Figure 1: The Study Area Map
Source: Modified and adopted from Administrative Map of Benue State (2024)

METHODOLOGY

Types and Sources of Data

The data used for this study were mainly secondary. This is briefly described in Table 1.

Table 1: Data types, Sources and Purpose

S/N	Data	Resolution/Scale	Source	Purpose
1.	Landsat 7 OLI_TIRS (2005)	30m ™	United States Geological Survey (USGS). (http://glovis.usgs.gov)	For the creation of land use/land cover map

2.	Landsat 8 OLI_TIRS (2015)	30m ™	United States Geological Survey (USGS). (http://glovis.usgs.gov)	For the creation of land use/land cover map
3.	Landsat 8 OLI_TIRS (2025)	30m ™	United States Geological Survey (USGS). (http://glovis.usgs.gov)	For the creation of land use/land cover map
4.	Administrative Map	30m ™	osgov.ng Nigeria Admirative Boundary	For the creation of a boundary
5	Sentinel–2 Data	10m	Sentinel Data Hub	NDVI creation

Data Pre-processing

Sub-setting and Projection

All the acquired datasets were extracted by mask to the boundary of the study area and projected to the Universal Transverse Mercator (UTM) Zone 32N coordinate system to enable area calculation, as it is impossible in the Geographic Coordinate System (GCS).

Layer Stacking

The Landsat 8 and 7 Operational land Imager (OLI) layer was stacked to produce a colour composite. The Satellite imagery was imported into ArcGIS 10.8 environment. A subset covering the area of interest was extracted from the larger scene of Landsat 8 and 7 of study area. This is necessary in enabling the process of combining multiple separate bands in order to produce a new multi band image.

Image Classification

Supervised classification was performed using a Maximum Likelihood Classifier. The supervised image classification categorizes an image's pixels into land cover classes based on user-provided training data. It has several advantages over simpler methods like unsupervised classification. First, because the classes are user-defined, they are ensured to conform to the classification hierarchy of the investigation. Second, the use of training data improves the ability to differentiate between

classes with similar colour profiles. Finally, the method tends to be more reliable and produce more accurate results (Shive and Crabtree, 2004).

The sample set of the satellite images were also created in ArcGIS 10.8, which contains the domain of all the land use/cover classes to be selected. The classification scheme that was adopted for this research is the United States Geological Survey (USGS) classification scheme level one (1), which provides a basis for land use/land cover assessment. The classification type to be adopted in this research are: (i) Built-up areas (ii) Water bodies, (iii) Vegetation (iv) Rock outcrop, and (v) Bare surfaces. The aerial extent of each land use/cover type will be automatically calculated by the computer. This method of classification involves the procedure of identifying pixels possessing the same spectral features. ERDAS Imagine software was used to digitally process and identify the spectral signatures of different features (ESRI classification, 2021).

Table 2: Land Use Land Cover Classes and Definitions

S/N	Land Use Land Cover Types	Definitions
1	Cropland	Human planted/plotted cereals and crops like corn, wheat, soybeans and fallow plots of structured land.
2	Forest (Trees)	Significant clustering of tall dense vegetation typically with a closed or dense canopy.
3	Shrubs	Moderate to sparse cover of bushes, shrubs and tufts of grass, savannahs with very sparse grasses, trees or others.
4	Built-Up Areas	Human-made structures; paved, roads and large homogenous impervious surfaces, including parking structures, office buildings, and residential housing; dense villages / towns / cities
5	Water bodies	Areas where water is available throughout the year.

Source: ESRI (2021)

RESULTS AND DISCUSSION

Land use and land cover changes are critical indicators of environmental and socio-economic dynamics. This table presents LULC data for four categories (Water Body, Vegetation, Built-up, and Bare land) for 20 years: 2005, 2015, and 2025. The data includes both the area in hectares (Ha) and the percentage (%) of total land cover for each category.

Table 4: Land use and Landcover Change from 2005 to 2025

Land Cover Types	**Year 2005**		**Year 2015**		**Year 2025**	
	Area (Ha)	%	Area (Ha)	%	Area (Ha)	%
Water Body	28876.85	16%	42216.47	20%	36762.78	17%
Vegetation	81389.08	45%	57964.28	27%	42999.23	20%
Built up	46480.78	26%	96842.13	45%	114745.60	54%
Bareland	23129.97	13%	16394.21	8%	18915.19	9%
Total	179876.69	100%	213417.10	100%	213422.80	100%

The results from the table revealed that from the year 2005 –2015, there is an increase in the water body from 16% to 20%, suggesting expansion, which could be attributed to flooding or reservoir construction in the study area. However, from 2015 – 2025, the water body decreased to 17%, which could possibly be as a result of drought, water extraction, or land reclamation by the people of the area. In addition, the initial increase followed by a decline could also reflect climate variability or human interventions like dam construction (Pekel et al., 2016). Sustainable water management is crucial to mitigate such changes (UNEP, 2021). For the vegetation, steady decline was observed from 45% (2005) to 20% (2025), indicating significant deforestation (agriculture or urban expansion). The decline in vegetation correlates with studies on deforestation driven by agricultural expansion and logging (Hansen et al., 2013). Such losses can exacerbate climate change by reducing carbon sequestration (IPCC, 2022). However, rapid growth in built-up were increased from 26% (2005) to 54% (2025), reflecting urbanization, population growth, and economic development. The dramatic rise in built-up areas mirrors findings by Seto et al. (2016), who highlighted that urban land expansion often outpaces population growth, especially in developing regions. This can lead to habitat fragmentation and loss of ecosystem services

(Güneralp et al., 2020). There is a fluctuating trend in bareland, which shows a decrease from 13% (2005) to 8% (2015), then slightly increased to 9% (2025), possibly due to land abandonment or degradation. The minor fluctuations may indicate land degradation or temporary land-use changes, as noted in studies on soil erosion and desertification (Cherlet et al., 2018). The possible cause of later increase in the barrenness could be attributed to abandoned farmland turning barren, land degradation (desertification, overgrazing), which are recently experiencing from the clashes between farmers and herders. The result also revealed a total land area change, for example, the year 2005 had 179,876.69 Ha, while in the year 2015, it was discovered that there was a (+19% increase) 213,417.10 Ha, and that of the year 2025 recorded 213,422.80 Ha, which is stable.

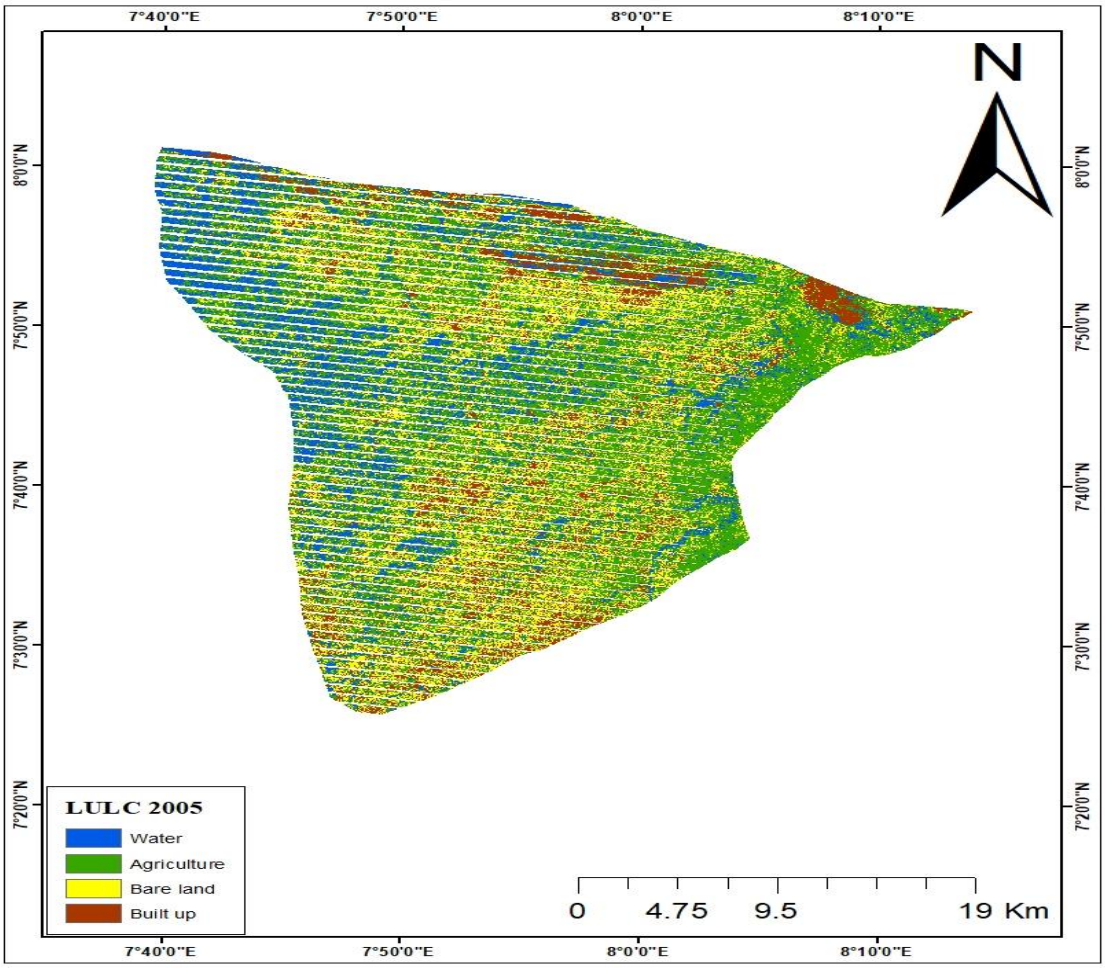

Figure 2: Land use and Landcover Map 2005

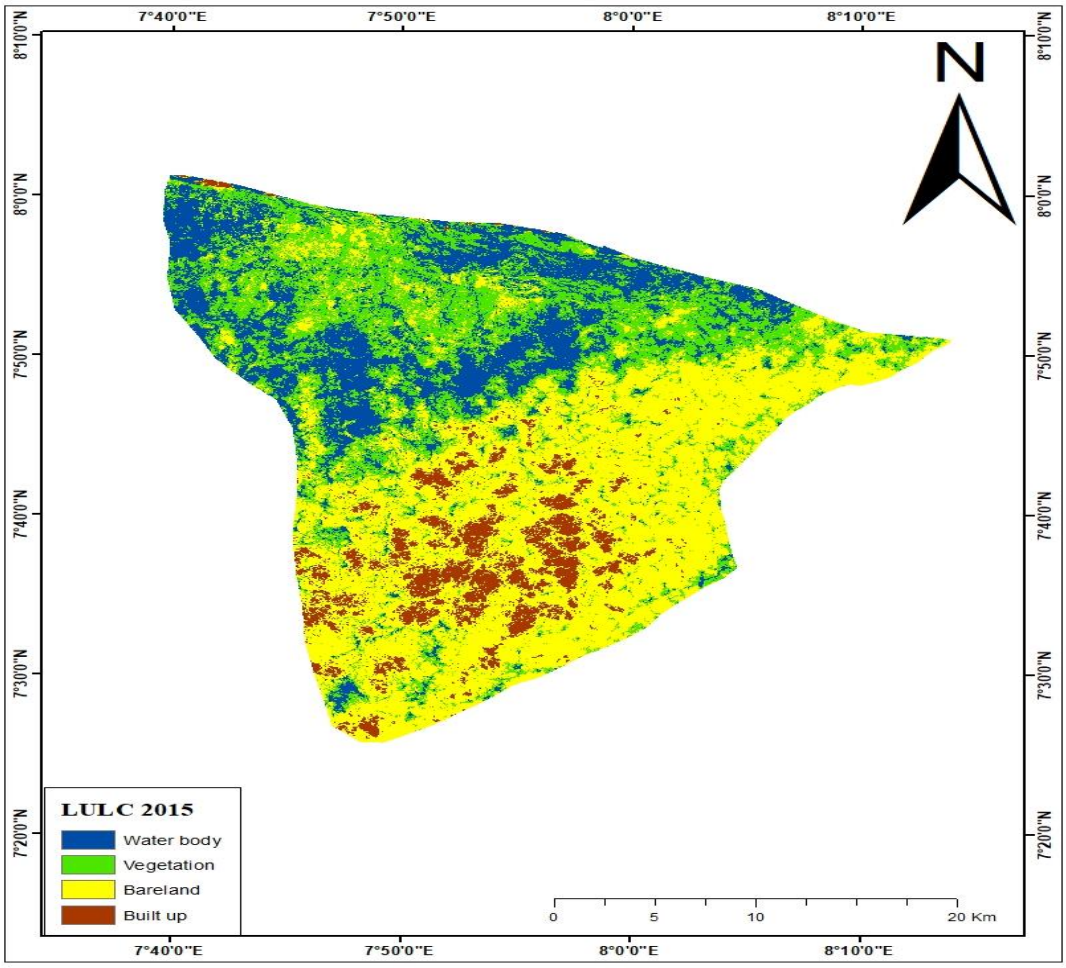

Figure 3: Land use and Landcover Map 2015

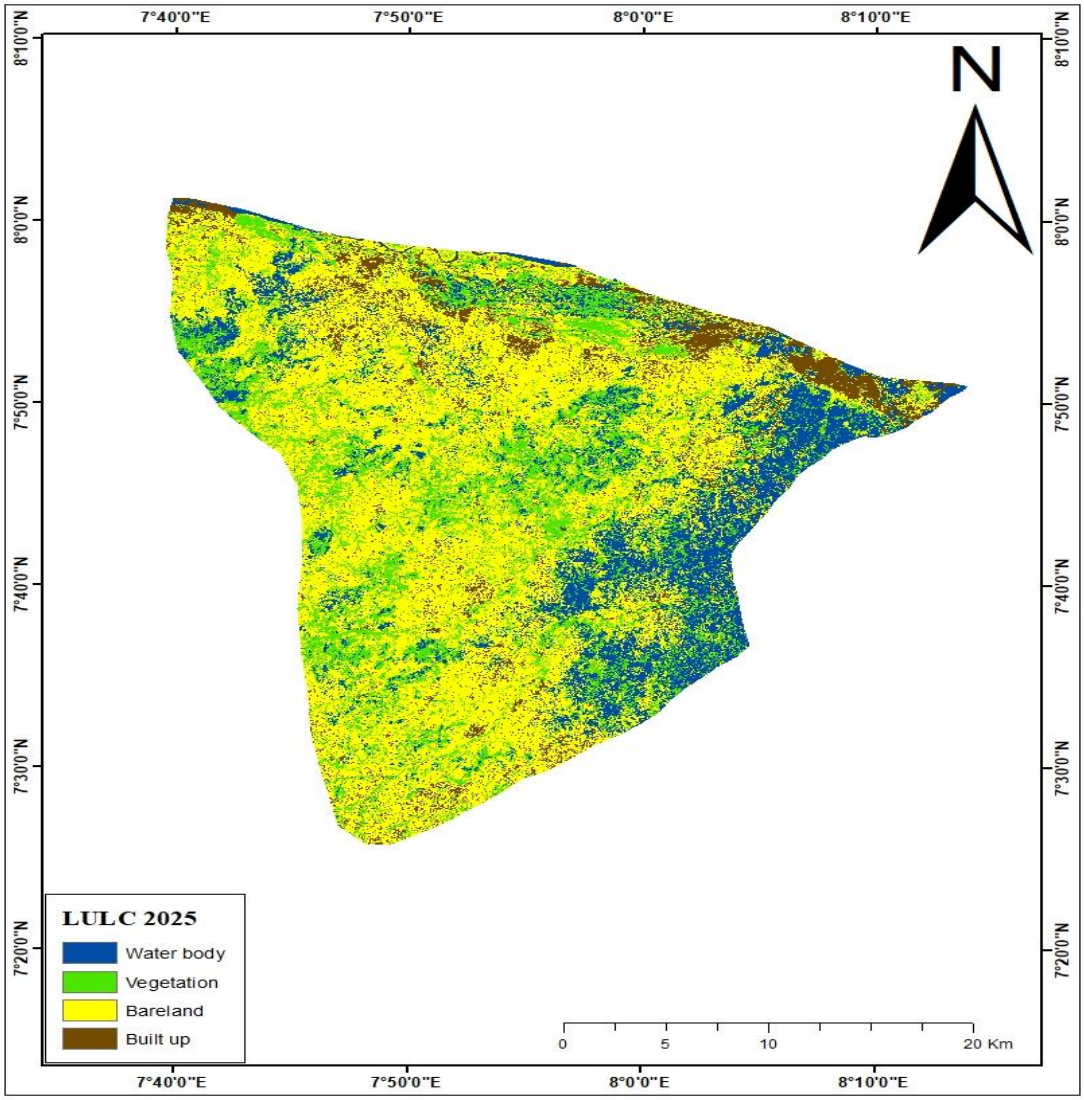

Figure 4: Land use and Landcover Map 2025

Accuracy assessment of Land use and Land cover

This table presents the accuracy assessment of the landuse and landcover. It shows the built up, water, vegetation as well as bare land.

Table 4.2: Land use Land Cover Accuracy Assessment

	Built up	**Water**	**Vegetation**	**Bare land**	**Producer's Accuracy**	**User's Accuracy**
Built up	47	0	1	2	94.0	94
Water	0	46	2	2	93.9	92
Vegetation	1	2	44	3	89.8	88
Bare land	2	1	2	45	86.5	90
Total	50	49	49	52		

Overall Classification Accuracy = 91%
Overall, Kappa Statistics = 0.88

Source: Authors' Analysis 2025

Evaluation of classification results is an important process in the satellite image classification procedure. This is necessary to ascertain the level of correctness and reliability of the classification output. The Kappa index, which provides a more rigorous assessment of classification accuracy was also computed. The Kappa coefficient expresses the proportionate reduction in error generated by a classification process compared with the error of a completely random classification. Table 4.2 reveals that the Landsat image of 2025 was classified into 4 LULC categories. Built-up and water were classified with a higher producer's accuracy of 94%, each while bare land and vegetation were classified with a lower producer's accuracy of 87% and 90%. The overall classification accuracy of the image was 91%, while the overall Kappa coefficient was 0.88.pow

CONCLUSION

Land use and land cover assessment play a significant role in land usage, management, and development. This work utilizes geospatial techniques in assessing the land use and land cover in some selected areas of Benue State. This study examines LULC transformations over a temporal scope of 20 years by using satellite imagery (Landsat data). The study concludes that from the year 2005 –2015, there is an increased in the water body which rouse from 16% to 20%, signifying expansion which could be attributed to flooding and decrease of 17% in the year 2015 – 2025 while vegetation declined was from 45% (2005) to 20% (2025), indicating significant deforestation (agriculture or urban expansion). However, there is a rapid growth in built up of 26% (2005) to 54% (2025) reflecting urbanization. Lastly, the study revealed an increase (+19%) 213,417.10 in landmass of the area (Ha).

RECOMMENDATION

Based on the result of the analysis, the study recommends

1. There should be an immediate implementation of urban growth boundaries by using the 2025 LULC map as a baseline and high-density zoning in existing built-up areas needs to be monitored in order to preserve remaining vegetation.
2. There should be public awareness campaigns to prioritize reforestation in areas with land abandonment (identified as zones of increasing bare land).
3. The government should implement and encourage agroforestry systems by combining food crops with native tree species

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IMPORTANCE OF AGROFORESTRY IN MITIGATION OF CLIMATE CHANGE AND FOOD SECURITY

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Abstract

This paper reviewed the importance of agroforestry in mitigation of climate change and food security. Agroforestry systems not only provide a great opportunity for sequestering carbon, and hence helping to mitigate climate change, but they also enhance the adaptive capacity of agricultural systems in tropical and subtropical regions. Agroforestry can be viewed as a societal response, primarily born out of a need to fulfill immediate basic human needs of food, fuel, fodder, shelter, protection etc. Through diverse food production, natural resource conservation, improving nutrition, health and increasing economic of rural poor people, agroforestry plays an important significance role in country's food security. Governments and institutions now can rebalance agricultural policy and investment toward such multi-goal approaches. In doing so, they could achieve important improvements on multiple international commitments around the interlinked themes of food security, climate change, biodiversity conservation, and social well-being.

Keywords*: climate change, food security, mitigation and agroforestry.*

Introduction

In the humid tropics, agroforestry systems are a part of a continuum of landscapes that include row crops, grasslands, managed forests, and primary forests. Many of these systems are perennial, with tree components that can remain in the field for more than 20 years, including agroforests and home gardens (Albrecht and Kandji, 2003). Agroforestry trees are essential because they improve the microclimate, cycle nutrients, and shade tree crops like cocoa. These systems are known as simultaneous systems because crops and trees grow simultaneously (Albrecht and Kandji, 2003).

Agroforestry is the intentional integration of trees and shrubs into crop and animal farming systems to create environmental, economic, and social benefits. Agroforestry is often considered a cost-effective strategy for climate change mitigation. Tree-based farming systems store carbon in soils and woody biomass, and they may also reduce greenhouse gas emissions from soils (Bryan *et al* 2013a). Agroforestry techniques are appropriate for landscape restoration because they can enhance soil characteristics and plant availability of water. Additionally, trees offer a variety of ecosystem services that are critical for reducing local populations' vulnerability and fostering resilience to climate change. These services include water regulation, climate buffering, soil fertility, erosion control, and flood control, in addition to providing food, fodder, medicine, and wood (Verchot *et al.,* 2007; Mbow *et al*., 2014). Agroforestry can very likely contribute to increasing the resilience of tropical farming systems. Our knowledge of agroforestry's ability to aid in climate change adaptation, however, is, at best, limited. More data is needed to fully understand how agroforestry mitigates floods and droughts from both a financial and biophysical perspective, including diversification and revenue risk as well as hydraulic lift and soil fertility. Agroforestry holds the potential to foster collaborations between initiatives aimed at mitigating climate change and those assisting marginalized communities in adjusting to its adverse effects.

Droughts, floods, and pests are among the agricultural risks that climate change may exacerbate. How successfully farmers adjust to the challenges posed by climate change will determine how long they can live on their land. There are various ways to use agroforestry to improve resilience in the landscape and adapt to climate change on farms. For example, agroforestry can improve atmospheric warming and cooling while lowering air pollution, resulting in a stable microclimate for animals and crops (Ellison *et al*., 2017). Climate change will affect developing countries more severely because of their low capacity for adaptation (IPCC 2001). Within these countries, the agricultural sector is particularly vulnerable, putting rural populations at risk. Furthermore, climate change is an additional threat that might affect a country’s ability to meet urgent rural

development demands including the improvement of food security, poverty reduction, and provision of an adequate standard of living for growing populations. Climate change can increase risk for agriculture such as droughts, flooding and pests. The ability of farmers to continue living on their land depends on how well they adapt to climate change risks. Agroforestry for climate adaptation at the farm level and enhanced resilience at the landscape level can take many forms. For instance, agroforestry can reduce air pollution and enhance both warming and cooling of the atmosphere, creating a resilient microclimate for crops and livestock (Ellison *et al*., 2017).

Agroforestry's contribution to food security and climate change goals

In agroforestry, the three mains components - animals, crops and trees - can be combined in numerous spatial and temporal arrangements and for different functions, creating thus many different kinds of systems. The definitions for the systems are described in figure 1.

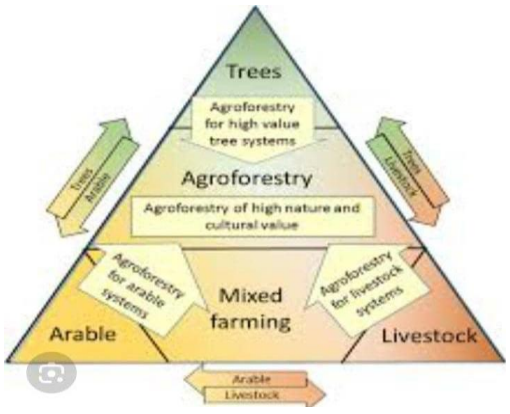

Fig. 1: Graphical illustration of Agroforestry systems

Agrisilvicultural System (Trees combined with crops): The agrisilvicultural system is a system that combines tree planting with crop production. This could either be in the form of home garden, alley cropping, taungya, improved fallow, multilayer tree garden, multipurpose trees on cropland, plantation crop combination, trees in soil conservation and reclamation, shelterbelts, windbreaks and live hedges, and fuel wood production (Adeyemi *et al*., 2020). Silvopastoral System (Trees and pastures or animals): The silvopastoral system of agroforestry is a system that integrates tree planting with pasture or livestock. This could either be in the form of trees on rangeland or pasture, plantation crops with pastures and animals, and protein banks.

Agrosilvopastoral Systems (Animals, trees and crops): This type of agroforestry practice involves the complex combination of trees, crops and livestocks. This could take the form of home garden involving animals, multipurpose woody hedgerows, apiculture with trees, and aqua forestry. The major aim of Agroforestry is to enhance positive interactions between trees, shrubs, food crops and livestock while maintaining soil fertility and adequate water balance. The overall concept is to improve net production from a given area of land without depending on costly farm inputs, which are usually unavailable to the rural farmers. Survey by FAO (2010) showed that tree crops and food

crops combinations dominate agriculture in the humid tropics and provide a stable food crop yield and income for subsistence farmers in the region. This appears to satisfy the needs of the rural farmer as food and wood can be produced at the same time in a sustainable manner thus making trees a productive part of the farming system as in the traditional system of shifting cultivation. Agroforestry has long been recognized in sustainable development models throughout the world due to the benefits they bring not only to the economy and society but also to the ecosystem. Several factors are responsible for the rising increase in agroforestry practice, some of which include; increased deforestation and scarcity of land because of population pressures, farming systems, climate change mitigation, and food system transformation. Agroforestry Models (Technologies) in Nigeria:

Homegarden: This is the planting of trees along with vegetables and food crops in free spaces around the homes. They could be arranged to include many multipurpose trees in multistory association with animal, crops and small livestock. Home gardens are very well developed in the southern part of Nigeria especially in the East. The food crops are integrated with trees behind homesteads. The smaller trees occur near the house while the bigger trees are at the border of the home farm. A lot of fruits, nuts, and grains have been known to be produced from this technology, generating a lot of income for the farmer. In the Northern part of Nigeria where participation by farmers is low for this technology, their major reason for planting home gardens is for food and fruits production (Adeola *et al*, 2000a). According to Adeola (2015b), of the few farmers practicing homestead in the semi-arid zone, the emphasis is on fodder for animals and shade around homestead. The major tree species used are fruit trees like *Magnifera indica, Psidium guajava*, *Anacardium occidentale*, *Moringa oleifera* and *Termarindus indica* (Adeola *et al,* 1995).

Taungya System: According to Adeola (2015a), taungya system involves the cultivation of food crops in forest reserves. Lands under forests are known to be fertile and in communities with limited land where there are government forest reserves; forest lands are distributed to land hungry farmers to grow their food crops after forest exploitation. Such farmers will however plant seedlings of government preferred tree crops on such land along with their food crops. The growth of food crops is temporary as the trees soon close canopy in one or two years and take over the entire land. Meanwhile, the farmer would have harvested his crops (usually maize, cassava, pepper, okra etc.) at the end of the first year. He could now be allocated another portion of forest land for clearing, packing, burning and planting for the next planting season. In this way, the farmer has fertile land to use, while the government obtains farmers' free labor to plant trees. Most plantations of teak and *Gmelina* along roadsides in the former western region of Nigeria were grown through this method.

Improved Fallow: This agroforestry technology involves the planting of leguminous and other soil improving trees species on fallow land. It was developed especially to replenish soil nitrogen on farm lands. It is increasingly adopted by farmers in southern, (eastern and western) Nigeria as well as in parts of West Africa (Adeola, 2015a). In the traditional farming system, trees/shrubs are preserved on fallows to allow the soil to recover some of its fertility. Under low population pressure and long fallows, soil fertility could usually be restored to an acceptable level before the farmer returns to the land again. Increased population has forced the farmers to reduce the fallow periods such that farmers now return to previously cultivated lands before soil fertility could be restored. This has often led to poor yield (Adeola, 2015a). The traditional farming system can no longer accommodate long fallows in many zones of the region. The improved fallow technology therefore involves the planting of short rotation, nitrogen-fixing trees on fallows for a period of time (usually between two and five years) followed by arable crops for some years. Trees like *Gliricidia sepium*, *Leucaena leucocephalla* and *Enterolobium cyclocarpum* have been used successfully in the humid region. Other species used include *Sesbania sesban* and *Tephrosia vogelii* in Eastern and Southern Africa (Adeola, 2015a).

Alley farming: Just like improved fallow, alley farming is an agroforestry based technology that can be used by small holder farmers in the humid tropics to control erosion. According to Adeola (2015a), this system combines both mulching and hedgerow barriers in reducing run-off and creating soil stability. The hedgerow crops are pruned and scattered on the alleys. This is usually done to provide nutrients to the soil but it helps to reduce water run-off and sand drift, minimizes rain drop impact, and reduces erosion/runoff. The hedgerow barriers are usually planted along the contours on sloppy lands. If planted at 3m/25cm apart, the hedges close gaps in time and are therefore able to prevent sand drift while the mulch reduces run off.

Windbreaks: These are strips of trees/shrubs planted to protect fields, homes, canals or other areas from wind and blowing soil or sand. It is planted to reduce soil erosion, improve microclimate for growing crops as well as shelter people and livestock. It can also improve and sustain crop yield (*Adeyemi et al.,* 2020). Usually, one or two rows of trees are established across the path of the prevailing wind. The length is usually across a farmers plot or property. Windbreaks are used both in Sahel and Sudan savanna. Major species used are *Azadiracta indica*, *Eucalyptus camadulensis* and *Prosopis juliflora* (*Adeola et al.,* 1995). Some of these species are also used for erosion control (Adeola, 2015b). Roadside planting: This is amenity planting 1 - 3 rows of trees along roadsides and in public spaces. Apart from beautification, the trees have an effect on the microclimate of the area. They provide shade

and protect the houses in the cities from storms which could otherwise be destructive (Adedire, 2014).

Agroforestry and Food System: Tree cover has been linked to greater dietary diversity (Ickowitz *et al.,* 2014), as all nuts and more than half of humanconsumed cultivated fruits grow on trees (Powell *et al.,* 2013)) most of which are rich in nutrients. Combining trees with crops, apart from providing important environmental services, help adapt and mitigate climate change, restore degraded lands, enrich biodiversity, while providing nutrient-dense crops. Agroforestry is one the few land use strategies that promises such synergies between food security and climate change mitigation (Mbow *et al*., 2014). It is also less likely than other strategies to negatively affect the provision of non-carbon ecosystem services, such as water cycle regulation (Smith and Olsen, 2010) or biodiversity conservation (Ravindranath, 2007), all of which are integral aspects of 'climatesmart agriculture. According to Amonum *et al*., (2012), agroforestry Programme as a practice is very useful in sequestering carbon and could be used on sustainable landscape management principle to address the needs of the stakeholders for food, fibre, fodder and energy as well as other services while still serving as carbon sink.

Agroforestry is an often named solution for the dual climate and food security challenges (Dinesh *et al*. 2017). Agroforestry practices, such as the integration of leguminous trees into fallow periods between two cropping seasons (improved fallow), or intercropping short- and long-term trees with crops (dispersed intercropping), can lead to higher crop yields in many parts of the tropics (Hall *et al*. 2005), and increased well-being (Thorlakson and Neufeldt 2012). Meanwhile, agroforestry can mitigate climate change through creating and enhancing carbon sinks by capturing carbon from the atmosphere through photosynthesis and storing it in biomass and soil (Albrecht and Kandji 2003). However, carbon stocks in agroforestry systems of the tropics vary even for similar types of agroforestry systems (Nair and Nair 2014) due to the diversity of agroforestry practices (e.g., homegardens, windbreaks, intercropping, woodlots, etc.) and the impact of environmental (e.g., access to soil moisture, light and nutrients) and management (e.g., pruning and felling) factors suggesting the potential for agroforestry to be a low emission development strategy may be site specific.

The contributions of agroforestry practices to the livelihoods of farmers are determined by local biophysical and socio-economic factors and need to be examined from their perspective (Dumont *et al*. 2017). The global benefit of regulating climate through carbon sequestration cannot be considered a motivating argument for smallholder farmers to invest in new farming practices (Bryan *et al.* 2013b). Therefore, mitigation efforts at smallholder farm level need

to produce tangible and direct livelihood benefits for farmers, such as being a source of food, fuel or fodder with mitigation being a co-benefit of the improved agricultural practice. The majority of studies only quantify either the amount of carbon stocks in smallholder systems (Henry *et al*. 2009) or the role of agroforestry in building resilience to climate-related hazards. Further, recent studies assessing carbon stocks often focus on particular agroforestry practices such as natural or planted fallows, agroforestry parkland and rangeland (Marone *et al.* 2017), or particular species such as coffee agroforestry (Guillemot *et al*. 2018) or cocoa agroforestry (Middendorp *et al*. 2018).

SYNERGIES BETWEEN FOOD SECURITY AND CLIMATE CHANGE MITIGATION

Many of the agricultural mitigation options are also able to provide benefits in terms of increased adaptation and crop productivity (FAO 2010). To a large extent, land use changes needed to generate climate change mitigation are the same as those that improve agricultural productivity and increase system resilience, at least in the long run (FAO 2009). Long-term impacts are expected to be positive for increasing both the average and stability of production levels. The potential for synergies between agriculture mitigation and food security is generally site specific, depending on the previous land use, type of farming system and institutional capacity. Some practices with high potential for synergies over a wide range of circumstances can, however, be identified, for example: avoiding bare fallow; incorporating crop residues; diversifying crop rotations to incorporate foodproducing cover crops and legumes; increasing fertilizer use efficiency (e.g. integrated fertility management or precision fertilizer applications); improving fodder quality and production; expanding lowenergy irrigation; expanding agroforestry; and adopting soil and water conservation techniques that do not take significant amounts of land out of food production. Agro-ecological conditions play a major role in determining whether synergies between mitigation and food security can be obtained. In particular, there is a major difference between humid verses dry areas in terms of the relative mitigation/food security impacts of changes in agricultural practices. Climate change mitigation has not traditionally been a driver of farmers' decisions, and it is unlikely to become a major driver in the future. Clearly, sequestering carbon on farms for the sake of climate change mitigation may not be attractive for an African smallholder farmer, especially if mitigation efforts do not lead to short-term increases in income or welfare. African farmers may be very reluctant to sacrifice any part of their often-meager farm incomes to sequester carbon. If such farmers are to contribute to mitigation anyway, carbon-sequestering land use strategies must either be subsidized, to an extent that makes them equivalent to foregone profits from alternative

land uses, or they must be profitable without any compensation. With bio carbon projects continuing to be challenged to overcome financial, institutional and governance hurdles, the greatest opportunity to sequester carbon on a large scale on Africa's farms is through innovations that enhance food security and provide mitigation services as a co-benefit (e.g. Increased parkland tree cover: this specifies to encourage farmers to identify, protect and stimulate the growth of naturally regenerating shrubs and trees in their fields. Multi-layered farming: this process of growing multiple crops in a single field. Intercropping: this is cultivation of two or more crops simultaneously on the same field. Land sharing practices: These practices enable biodiversity to be maintained within agricultural landscapes. (Beddington, *et al,* 2012).

ENABLING FACTORS AND BARRIERS TO THE IMPLEMENTATION AND SCALING-UP OF AGROFORESTRY

Agroforestry is a widespread practice in both developing and developed countries, and its visibility is increasing at national level and in international institutions. However, there are a number of barriers working at different scales that are preventing a broad-scale implementation of agroforestry practices, such as inefficient markets, unclear land-rights, limited access to knowledge and finance and lack of intersectoral collaboration (Agroforestry Network, 2018). The Agroforestry Network proposes key enabling actions to scaling-up agroforestry , which include:

- ✓ Improving access to credit and monetary resources, e.g. by supporting scalable financial models addressing long-term returns on investment in agroforestry practices.
- ✓ Improving farmers' access to markets and creating value chains for agroforestry products.
- ✓ Improving farmers' access to high-quality planting material and extension services.
- ✓ Improving demand driven, participatory and inclusive agroforestry-related research.
- ✓ Create partnership between companies with sustainability profiles and agroforestry farmers. Farmers could be given a premium price for their products without certification and the companies promote agroforestry products using a storytelling approach.
- ✓ Implement minimum prices for certain agroforestry products that are linked to biodiversity conservation. Could be involved both government and larger companies.

AGROFORESTRY FOR ADAPTATION AND ECOSYSTEM RESILIENCE

Climate change can increase risk for agriculture such as droughts, flooding and pests. The ability of farmers to continue living on their land

depends on how well they adapt to climate change risks. Agroforestry for climate adaptation at the farm level and enhanced resilience at the landscape level can take many forms. For instance, agroforestry can reduce air pollution and enhance both warming and cooling of the atmosphere, creating a resilient microclimate for crops and livestock (Ellison *et al*., 2017).

Agroforestry is increasingly recognized as a land management system that can serve as a response option for both climate change adaptation and mitigation, while addressing many of the challenges that smallholder farmers are facing. Agroforestry can generate multiple livelihood and environmental benefits, as it can help to mitigate climate change and help farmers to adapt to extreme and variable weather (IPCC, 2019). Agroforestry supports tree-related ecosystem services, such as regulation of water and sediment flows, carbon and nutrient cycling in soils and it provides habitat for biodiversity. This leads to increased soil fertility, reduced soil erosion and flood and pest control. Benefits of agroforestry to smallholder farmers include increased farm productivity and reduction of external inputs such as conventional fertilizers and chemicals for pest management, leading to increased income.

SIGNIFICANCE OF AGROFORESTRY IN FOOD SECURITY AND CLIMATE CHANGE

- ✓ Enhance food production: By adopting agroforestry practices, smallholder farmers are able to increase their food security while simultaneously sequestering carbon from the atmosphere, bettering their economic opportunities, and enhancing other essential ecosystem services. Through appropriately combining plants, animals, and trees in agroforestry systems, farmers not only increase farm yields, therefore increasing food security, but also promote ecological and social resilience to change.
- ✓ Improve soil fertility: Agroforestry can take many forms from rotating animals through an orchard; to alley cropping rows of crops between rows of fruit, nut, or timber trees; to planting rows of windbreaks along the edges of your property, to planting shade-tolerant crops under the shade of a managed forest or orchard; and so much more. No matter what your agroforestry system looks like, incorporating trees improves soil fertility by increasing organic matter, boosting microbiological activity, mineralizing nutrients into a more plant-available form, cycling nutrients up from deep soil layers to shallow ones, fixing nitrogen (in the case of leguminous trees), and preventing nutrient losses due to leaching, erosion, and runoff. (Young, 1989).

- ✓ Improve soil Tree fallows: An improved fallow is defined as enrichment of a natural fallow with trees, shrubs or herbaceous legumes planted at high density to improve soil fertility. Improved tree fallows have the potential to increase crop yields while also providing wood.
- ✓ Soil amelioration: The influence of agroforestry on soil quality through changes in ecosystem functions and services caused by direct and indirect effects of trees varies depending on the crop type, climate, and geography.
- ✓ Soil Conservation: Soil conservation is described as soil fertility maintenance through control of erosion, maintenance of organic matter, soil physical properties, nutrients and avoidance of toxicities (Young, 1989). Soil and water are conserved through reduction in soil loss from runoff and increasing of infiltration rate. The only crop is not enough to lower the velocity of runoff. When trees are grown with crops gives much strength to the soil through the permeability of water, as a result, water is also conserved. Trees with deep root system improve groundwater quality through trapping of nutrient, metals which are deposited in surface and subsurface of soil. (Dury, 1991).

Conclusion

Like few other land use options, agroforestry has real potential to contribute to food security, climate change mitigation and adaptation, while preserving and strengthening the environmental resource base of Africa's rural landscapes. It has a key role to play in landscape-scale mitigation schemes under the reducing emissions from deforestation and forest degradation REDD + or AFOLU (Agriculture, Forestry and other land uses) concepts. For millions of African farmers whose livelihoods are threatened by climate change and land degradation agroforestry offers a pathway toward more resilient livelihoods, the impact of climate change will be felt on several levels in the agricultural sector. Most of the effects will hit the rural poor in developing countries, who are the most vulnerable because of their poor ability to adapt. However, not all agroforestry options are viable everywhere, and the current state of knowledge offers very little guidance on what systems work where, for whom and under what circumstances.

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COMPARATIVE STUDY OF NUTRIENT COMPOSITIONS OF LEAF, PULP AND SEED OF *Tetrapleura teraptera* IN UMUDIKE, ABIA STATE, NIGERIA

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Abstract

Air-dried leaf, pulp and seed from a single *Tetrapleura tetraptera* mother tree were analysed in the Laboratory for nutrient compositions. SPSS version 25.0 was used for data analysis and the results showed significant differences ($p<0.05$) in proximate, mineral and vitamins compositions of *T. tetraptera* leaf, pulp and seed except vitamin C contents. *T. tetraptera* leaf, pulp and seed demonstrated good sources of food nutrients (Table 1, 2 and 3). Promoting its cultivation in homegardens and through afforestation programmes will enhance its availability for local and industrial uses.

Keywords: *Tetrapleura tetraptera*, leaf, pulp, seed and nutrient compositions

Introduction

The tropical regions of the world are richly endowed with abundant renewable edible forest plant and animal resources, which exist in form of honeybee products, leafy vegetables, edible oils, spices, alcoholic drinks, snails, stimulants and medicinal plants. Forest plant and animal resources are estimated to contribute largely to the livelihood, dietary diversity and nutrient density of over one billion people living in forested regions of the world (FAO, 2022).

Tetrapleura tetraptera is a forest food plant species with numerous medicinal, nutritional and economic benefits (Akintola *et al*., 2015). It exhibits potential medicinal qualities and aroma and is used in a variety of culinary delights (Aladesanmi, 2021). It is also applied in perfumes, pomades, alcoholic beverages, and biscuit production as a flavoring agent (Adusei *et al*., 2019; Mensah *et al*., 2024). Given the chemical composition and biological properties of *T. tetraptera*, it has the potential to be used in ethnomedicine, pharmaceutics, and industrial food productions such as functional food formulations (Ozaslan *et al*., 2016; Enwere, 2022). Functional foods improve human health by combating malnutrition as well as acute and chronic ailments including cardiovascular diseases, cancer, and diabetes (Anil *et al*., 2022;

Chikara and Panghal, 2022; Mensah *et al*., 2024). They can be used as a food supplement providing essential nutrients to the human body (Mensah *et al*., 2024).

Tetrapleura tetraptera belongs to the Fabaceae family. It is indigenous to Africa, particularly common around the fringes of West African rainforest belt and grows up to 20-25 meter high, with a diameter at breast height (DBH) of 1.5 - 3.0m (Orwa *et al*., 2019). It produces reddish wood used locally for building poles, pestles, tool handles and carvings (Orwa *et al*., 2022). *Tetrapleura teraptera* is described with various indigenous names in Nigeria as Aridan (Yoruba), Ighimiaka (Edo), Uhiokirihio (Igbo), Apapa (Ijaw), Dawo (Hausa) and Ikyho (Tiv).

Prior researches on *Tetrapleura tetraptera* have mostly concentrated on the nutritive value, biological properties and health benefits of the fruit. There is still significant research gap when it comes to comparing of nutrient compositions of the leaf, pulp and seed. It is expected that such research will further divulge more invaluable information on *T. tetraptera* which will be applicable in various essential fields of mankind.

Materials and method

Sample preparation and laboratory analysis

Dried matured *Tetrapleura tetraptera* pods from a single mother tree were sourced from the Seed Bank of the Department of Forestry and Environmental Management, Michael Okpara University of Agriculture, Umudike. Umudike lies on Latitude 4.90794 and 4.90809^{o}N and Longitude 6.92413 and 6.92432^{o}E (Chima *et al*., 2017); 122m above sea level (Nwosu *et al*., 2011). The rainfall pattern of the area is that of bimodal distribution with annual rainfall range from 1500-3000mm.

The pods were extracted of seeds, leaving the pulp. Both the pulp, seeds and air-dried leaves from the *Tetrapleura tetraptera* mother tree were taken to the Central Laboratory of the National Root Crops Research Institute (NRCRI) Umudike, Abia State, Nigeria for analysis.

Proximate analysis - moisture content, ash content, crude fiber, crude fat, crude protein, carbohydrate were determined based on the official analysis methods by Association of Official Analytical Chemists (AOAC, 2003); Mineral content analysis - Iron (Fe) and magnesium (Mg) determined by atomic absorption spectrometry and Sodium (Na), potassium (K) and phosphorus (P) by flame photometry according to the methods of Association of Official Analytical Chemists (AOAC, 2003) while Vitamins content analysis – vitamin A, vitamin B1, vitamin B2, vitamin B3, vitamin C and vitamin E were determined according to the methods of Association of Official Analytical Chemists (AOAC, 2003).

Data analysis

All the data collected were analyzed using Analysis of Variance (ANOVA) at 0.05 probability level and all Posthoc tests were carried out using Tukey-test. Software SPSS version 25 (2017) for windows was used for the Statistical Analysis.

Results and discussion

Proximate composition of *Tetrapleura tetraptera* leaf, pulp and seed

Table 1 reveals significant variation ($P<0.05$) in moisture content of *Tetrapleura tetraptera* leaf (6.59%), pulp (8.80%) and seed (7.35%). The high moisture content of pulp is attributed to the presence of parenchyma cells, which are specialized for storage and have a high capacity for retaining water (Ahmed, 2020). Generally, the respective moisture contents of *Tetrapleura tetraptera* leaf, pulp and seed are lower than that obtained in *Cola rostrate* leaf (15.79%) and fruit pulp (56.56%) (Mukah *et al*., 2023). The higher moisture content of *Tetrapleura tetraptera* pulp indicates its nutritious and hydrating potential for various health benefits and can be valuable components of a balanced diet. Dry matter refers to the portion of plant material that remains after the water content is removed, comprising carbohydrates, proteins, fats, vitamins, and minerals. *Tetrapleura tetraptera* leaf had higher dry matter content (93.66%) than pulp, (92.65%) and seed (91.20%). Comparatively with other fruits, *T. tetraptera* leaf (93.66%) contained higher dry matter than that of *Moringa oleifera* leaf (88.40%) (Adeoye *et al*., 2021) and lower dry matter than *Telfairia occidentalis* leaf (96.50%) (Onuorah *et al*., 2022). These findings reflect the nutritional richness of *Tetrapleura tetraptera* fruit (Olatunji, 2022). Total ash represents the total mineral content in a sample, obtained as inorganic residue after the combustion of organic matter. The total ash content in *Tetrapleura tetraptera* leaf, pulp and seed varied significantly with the seed having the highest ash content (7.48%), pulp (5.80%), and leaf (3.62%). Compared to other plants, *T. tetraptera* seed had higher ash content than *Parkia biglobosa* seed (4.85%) (Musa *et al*., 2020). The high ash content in *T. tetraptera* seeds suggests its potential as a significant source of minerals such as calcium, magnesium, and potassium that support bone health, muscle function, and various metabolic processes; and this can benefit populations facing mineral deficiencies (Olajide, 2021). Promoting the cultivation of this plant can help meet mineral needs in communities, especially where access to mineral-rich foods is limited. Crude fibre refers to the indigestible part of plant materials, primarily cellulose and lignin, which supports digestive health by promoting bowel movements. *T. tetraptera* pulp had the highest crude fibre content (10.68%), seed (6.27%) and leaf (2.40%).

Tetrapleura tetraptera pulp had higher crude fibre than *Adansonia digitata* pulp (8.50%) (Adeolu *et al*., 2022). *Tetrapleura tetraptera* high pulp fibre content signifies its role as a functional food for promoting digestive health. Olayinka (2021) opined that foods rich in crude fibre help regulate cholesterol levels and prevent digestive issues such as constipation. The incorporation of *Tetrapleura tetraptera* pulp into the diet can improve gut health, reduce the risk of cardiovascular diseases, and support weight management. Total fat content measures the lipid concentration in a sample, which serves as a source of energy and essential fatty acids. *Tetrapleura tetraptera* total fat content in leaf, pulp and seed varied significantly. The leaf had 2.08%, pulp - 6.23% and seed - 21.50% total fat contents. Similarly, *T. tetraptera* seed had higher total fat content than *Cucumismelo* seed (14.20%) (Okoro *et al*., 2021). High-fat content in *T. tetraptera* seed indicates its excellent source of energy and essential fatty acids, such as omega-3 and omega-6, which are vital for brain function and heart health. Seeds with high lipid content can support cellular functions, promote heart health, and improve cognitive function (Adebayo, 2020). Incorporating *T. tetraptera* seeds into meals can enhance dietary fat intake, benefiting overall energy levels and providing essential fatty acids crucial for brain development and cardiovascular health. Additionally, the seeds could be used in food processing for oil extraction, further promoting their economic and nutritional value. Crude protein refers to the total protein content in a food sample, reflecting the amount of nitrogen present, which is crucial for muscle repair, enzyme production, and overall growth. Crude protein was highest in *T. tetraptera* seed (20.48%) followed by the leaf (18.82%), and the pulp (9.72%); also higher than that of *Cajanus cajan* seed (17.60%) (Ibe *et al*., 2022). *T. tetraptera* seed can serve as rich source of essential amino acids needed for growth and repair of body tissues. Foods rich in protein are essential for maintaining muscle mass, supporting immune function, and promoting overall health (Balogun, 2021). Incorporating *T. tetraptera* seeds and leaves into the diet can help improve protein intake, contributing to better physical development and immune response, especially in malnourished populations. This also positions the plant as a valuable crop for cultivation in areas where access to animal protein is limited. Carbohydrates are the primary energy source for the body, and their content is critical for assessing the energy-yielding potential of food. The *T. tetraptera*, leaf had the highest carbohydrate content (66.49%), followed by the pulp (56.73%), and the seed (36.94%). This high carbohydrate content within the *T. tetraptera* leaf and pulp indicates it as excellent source of energy, especially for individuals needing high-energy foods.

Carbohydrate-rich foods are essential for physical activities, brain function, and maintaining energy levels throughout the day (Oduro *et al*., 2007). Energy content measures the caloric value of food, reflecting its capacity to supply energy when consumed. The energy content in *T. tetraptera* leaf, pulp and seed varied significantly with the highest energy content found in the seed (423.14 Kcal/J), leaf (359.94 Kcal/J), and pulp (340.28 Kcal/J). Comparatively, *T. tetraptera* seeds had higher energy content than the *Balanites aegyptiaca* seeds (400 Kcal/J) (Adesina *et al*., 2019). This high energy content suggests that the seeds might be a significant source of calories, making them an ideal food for individuals requiring high energy intake like the athletes or those in physically demanding occupations. Aliyu *et al*. (2021), opined that foods with high caloric value are essential for maintaining energy balance, particularly in individuals with increased caloric needs. Including the seeds in diets can provide sustained energy, helping to meet the caloric demands of physically active individuals and those recovering from illness. This highlights the importance of cultivating *T. tetraptera* in afforestation programs, as it can serve as a sustainable source of high-energy food for local populations.

Table 1: Proximate composition of *T. tetraptera* leaf, pulp and seed

Plant part	Moisture (%)	Dry matter (%)	Total ash (%)	Crude fibre (%)	Total fat (%)	Crude protein (%)	Carbohydrate (%)	Energy (Kcal/J)
Leaf	6.59±0.03^{c}	93.66±0.22^{a}	3.62±0.03^{c}	2.40±0.03^{c}	2.08±0.05^{c}	18.82±0.09^{b}	66.49±0.01^{a}	359.94±0.15^{b}
Pulp	8.80±0.04^{a}	92.65±0.04^{b}	5.80±0.05^{b}	10.68±0.05^{a}	6.23±0.05^{b}	9.72±0.09^{c}	56.73±0.03^{b}	340.28±0.01^{c}
Seed	7.35±0.03^{b}	91.20±0.03^{c}	7.48±0.03^{a}	6.27±0.03^{b}	21.50±0.07^{a}	20.48±0.18^{a}	36.94±0.08^{c}	423.14±0.23^{a}

$^{a-c}$ = means with different superscripts within a column are significantly different (P<0.05).

Mineral composition of *Tetrapleura tetraptera* leaf, pulp and seed

Table 2 reveals significant differences in the mineral contents of T. tetraptera leaf, pulp and seed. Magnesium was significantly (P<0.05) high in *T. tetraptera* leaf (235.17 mg/100g), followed by the seed (189.64 mg/100g) and the pulp (121.93 mg/100g). This is consistent with that of *Moringa oleifera* leaf (200.00 mg/100g) (Ibe *et al*., 2022). Magnesium plays important roles in numerous biological processes, including energy production, muscle contraction, and nerve function. It is vital for the synthesis of proteins and DNA, as well as the regulation of calcium levels in the body. Sodium composition of *T. tetraptera* leaf, pulp and seed significantly varied (P<0.05) (Table 2), revealing highest sodium level in the seed (56.52 mg/100g), followed by the pulp

(34.63 mg/100g) and the leaf (21.64 mg/100g). Okoro *et al*. (2021) noted a lower sodium level (29.00 mg/100g) in *Glycine max* seed. Sodium is an essential electrolyte vital for fluid balance, muscle contractions, and nerve signal transmission. It plays a crucial role in maintaining blood pressure and supporting cardiovascular health. However, excessive sodium intake can lead to health issues such as hypertension. The higher sodium concentration in the seed may help support fluid balance and overall hydration, emphasizing the nutritional relevance of *T. tetraptera* in diets. Phosphorus was highest in the pulp (294.45 mg/100g); seed (245.71 mg/100g) and the leaf (197.74 mg/100g). Phosphorus helps in energy metabolism, bone formation, and cellular function. It is a key component of ATP (adenosine triphosphate) and is involved in DNA and RNA synthesis. Promotion of consumption of *T. tetraptera* in communities can enhance their phosphorus intake, overall health and well-being. Potassium contents of *T. tetraptera* leaf, pulp and seed varied significantly ($P<0.05$) with the seed potassium content higher (821.96 mg/100g) than those of pulp (686.61 mg/100g) and leaf (547.49 mg/100g). Potassium is an essential mineral that helps maintain fluid balance, supports muscle contractions, and regulates nerve signals. It is particularly important for cardiovascular health, as adequate potassium intake is associated with lower blood pressure. The significant potassium levels in both the seed and pulp of *T. tetraptera* in local diets can promote people's overall health being. The Iron contents of *T. tetraptera* leaf, pulp and seed varied significantly ($P<0.05$) with the iron content of the pulp higher (41.11 mg/100g), followed by that of the seed (19.59 mg/100g) and the leaf (8.42 mg/100g). Iron (Fe) is an essential mineral that plays a critical role in oxygen transport, energy production, and immune function. These findings align with that of Marcu (2018) on *Moringa oleifera* leaf (30.00 mg/100g of iron) and *Parkia biglobosa* seeds (18.00 mg/100g of iron) (Aliyu *et al*., 2021). Promoting *T. tetraptera* consumption can enhance iron intake, particularly in populations at risk of deficiency, thereby improving nutritional status and health outcomes.

Table 2: Mineral composition of *Tetrapleura tetraptera*

Plant part	Mg (mg/100g)	Na (mg/100g)	P (mg/100g)	K (mg/100g)	Fe (mg/100g)
Leaf	235.17 ± 0.21^{a}	21.64 ± 0.19^{c}	197.74 ± 0.19^{c}	547.49 ± 0.19^{c}	8.42 ± 0.15^{c}
Pulp	121.93 ± 0.36^{c}	34.63 ± 0.27^{b}	294.45 ± 0.21^{a}	686.61 ± 0.19^{b}	41.11 ± 0.28^{a}
Seed	189.64 ± 0.21^{b}	56.52 ± 0.27^{a}	245.71 ± 0.23^{b}	821.96 ± 0.39^{a}	19.59 ± 0.16^{b}

$^{a-c}$ = means with different superscripts within a column are significantly different ($P<0.05$).

Vitamin composition of *Tetrapleura tetraptera*

Table 3 shows the significant difference (P<0.05) between the Vitamin A content of leaf, pulp and seed of *T. tetraptera*. The pulp had the highest Vitamin A content (486.11 mg/100g), seed (402.19 mg/100g) and leaf (236.87 mg/100g). Vitamin A is essential for various physiological functions, including vision, immune function, and cellular communication. Vitamin A plays critical roles in maintaining healthy skin and mucous membranes (Smith *et al*., 2022). Adequate Vitamin A intake can reduce the risk of various health issues, including visual impairment and weakened immune responses (Johnson, 2020). Vitamin B1 (Thiamine) content of *T. tetraptera leaf, pulp and seed* varied significantly (P<0.05) (Table 3). The leaf had the highest concentration of Vitamin B1 (0.85 mg/100g), followed by the seed (0.54 mg/100g) and the pulp (0.74 mg/100g). Vitamin B1 (thiamine) plays a vital role in carbohydrates conversion into energy, making it essential for maintaining optimal bodily functions (Brown *et al*., 2023). These findings align with the work of James *et al*. (2021), who reported a range of 0.5 to 0.7 mg/100g of Vitamin B1 in various legumes. In contrast, Thompson *et al*. (2022) noted a higher concentration of 1.2 mg/100g in the seeds of *Phaseolus vulgaris*. The pulp had highest Vitamin B2 (Riboflavin) content (0.63 mg/100g); the leaf, 0.39 mg/100g, and the seed, 0.48 mg/100g. Vitamin B2 (Riboflavin) is essential for energy production and cellular function. It also plays a key role in maintaining healthy skin and vision. Riboflavin acts as a coenzyme in various metabolic processes, making it vital for overall health (Green *et al*., 2022). *Moringa oleifera* leaf is reported to contain 0.65 mg/100g Riboflavin (Wilson *et al*., 2021) and 0.9 mg/100g in the pulp of *Passiflora edulis* (Clark *et al*., 2020).

Tetrapleura tetraptera leaf, pulp and seed Vitamin B3 (Niacin) content varied significantly (Table 3). The pulp had highest concentration of Vitamin B3 (2.08 mg/100g), seed (1.56 mg/100g), and leaf (1.06 mg/100g). Vitamin B3 (Niacin) is important for converting nutrients into energy and maintaining healthy skin and nerves. According to Okwu *et al*. (2021), it also plays a role in DNA repair and stress responses. In the analysis of *T. tetraptera*. These findings are comparable to the study by Robinson *et al*. (2021), which reported 1.5 mg/100g in the seeds of *Glycine max*. In contrast, Taylor *et al*. (2022) found 2.5 mg/100g in the leaves of *Allium sativum*. The high levels of Vitamin B3 in the pulp of *T. tetraptera* indicate its potential role in promoting energy metabolism and overall well-being, which is crucial for populations relying on plant-based diets.

The Vitamin C contents of *T. tetraptera* leaf, pulp and seed varied not significantly (P>0.05) (Table

5). Vitamin C (Ascorbic acid) is a powerful antioxidant that supports the immune system, enhances iron absorption, and promotes skin health. According to White *et al*. (2023), adequate Vitamin C intake is essential for preventing scurvy and maintaining healthy connective tissues. Comparative research by Lee *et al*. (2021) indicated a range of 10-15 mg/100g in *Citrus* fruits, while Ojewole (2018) reported even higher levels of 20 mg/100g in the fruit of *Malus domestica*.

Vitamin E contents among the leaf, pulp and seed varied significantly ($P<0.05$) (Table 5). The seed contained the highest Vitamin E concentration (15.75 mg/100g), followed by the leaf (10.23 mg/100g) and the pulp (8.46 mg/100g). Vitamin E is a fat-soluble antioxidant that protects cells from oxidative damage and plays a role in immune function. According to Gray *et al*. (2022), Vitamin E is vital for maintaining skin health and promoting cardiovascular health. These findings are consistent with those of Clark *et al*. (2020), who reported 12 mg/100g in the oil of *Helianthus annuus*. In contrast, Johnson *et al*. (2021) found 9mg/100g in the leaves of *Spinacia oleracea*. The high Vitamin E content in the seeds of *T. tetraptera* underscores its potential role in protecting against oxidative stress and promoting overall health, suggesting it could be a valuable addition to the diet for enhancing cardiovascular health and skin integrity.

Table 3: Vitamin composition of *T. tetraptera*

Plant part	Vit. A (mg/100g)	Vit.B1 (mg/100g)	Vit.B2 (mg/100g)	Vit.B3 (mg/100g)	Vit.C (mg/100g)	Vit.E (mg/100g)
Leaf	236.87 ± 1.93^{c}	0.85 ± 0.03^{a}	0.39 ± 0.01^{c}	1.06 ± 0.02^{c}	9.90 ± 1.10^{a}	10.23 ± 0.01^{b}
Pulp	486.11 ± 1.93^{a}	0.74 ± 0.3^{a}	0.63 ± 0.01^{a}	2.08 ± 0.02^{a}	14.30 ± 1.10^{a}	8.46 ± 0.01^{c}
Seed	402.19 ± 0.97^{b}	0.54 ± 0.03^{b}	0.48 ± 0.01^{b}	1.56 ± 0.02^{b}	12.10 ± 1.10^{a}	15.75 ± 0.02^{a}

$^{a-c}$ = means with different superscripts within a column are significantly different ($P<0.05$).

Conclusion and Recommendations

This study revealed that the leaf, pulp and seed parts of *Tetrapleura tetraptera* are rich sources of food nutrients needed for human growth and development. The proximate composition analysis highlighted notable differences in nutritional contents among the plant parts. The leaf showed a low moisture content, with a high value of dry matter and carbohydrates, identifying it as excellent source of energy. The pulp had high moisture and crude fibre contents while the seed was richer in total ash, crude protein, total fat and energy. The mineral composition analysis revealed higher moisture in the *T. tetraptera* leaf than the pulp and seed; higher concentration of

phosphorus and iron in the pulp and higher sodium and potassium in the seed. The pulp was exceptionally high in vitamin A, which is essential for vision and immune function; and vitamins B1, B2, B3, and C. Inclusion of *T. tetraptera* in daily human diets will contribute to improved public health and food security. Promoting its cultivation in homegardens and through afforestation programmes will enhance its availability for local and industrial uses.

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SUSTAINABLE PRODUCTION OF WOOD CONSUMPTION IN NIGERIA

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Abstract

Nigeria has abundant forest resources that contribute significantly to economic growth, job creation, and environmental sustainability. However, the country confronts rising issues because of unsustainable wood production techniques, illicit logging, and deforestation, which endanger biodiversity, disturb ecosystems, and contribute to climate change. This paper conducts a thorough examination of the current situation of Nigeria's wood sector, analysing the socioeconomic ramifications of unsustainable resource extraction as well as the environmental effects of insufficient forest management. This paper highlights important gaps moreover, potential for promoting sustainable wood production and responsible consumption by assessing current policies, regulatory frameworks, and industry practices. The findings highlight the critical need for stronger legal enforcement, better forest administration, and increased community involvement in sustainable forest management. In order to promote responsible wood utilization in Nigeria, It also highlight significance of market-driven sustainability incentives, afforestation initiatives, and technological advancements. It also highlights the necessity of multi-stakeholder engagement and integrated policy reforms for sustainable forest resource management.

Keywords: sustainable, wood production, forest resources, deforestations, afforestation strategies, socio-economic impact

INTRODUCTION

Nigeria is blessed with enormous forest resources that are extremely important for the economy, ecology, and the livelihoods of millions of people. The forest accounts for 10% of the land area, providing important resources to millions of people (FAO, 2018). Nigeria's forests provide timber, fuel trees, and non-timber forest products, which are important sources of income and life for many rural population groups (Food and Agriculture Organization, 2018). Furthermore, forests make

an essential contribution to biodiversity, soil fertility, and carbon content. All of these are extremely important to reduce the outcomes of climate change. Forests are for wooden products, not to mention fun, beauty, wildlife, clean air, and water. Nigeria is equipped with enormous forest resources that play an important role in the country's economy, environment, and the livelihoods of millions of citizens (Oyediji and Adenika, 2022). However, Nigeria faces serious challenges related to the sustainable management of forest resources, threatened by deforestation, agricultural expansion, urbanization, and deforestation driven by non-durable timber harvesting (Agyemang, *et al*., 2024). According to FAO (2023), the country experiences one of the highest deforestation rates in the world, with an estimated loss of 350,000 hectares of forest per year. The consequences of these practices are bad, which lead to the destruction of living spaces, loss of biological diversity, and degradation of ecosystem services, which are extremely important for human survival (Ota, 2019).

Sustainable wood production involves practices that meet current needs without affecting future generations' ability to meet their needs (Ojo and Ayeni, 2019) while IPCC (2019) emphasizes responsible management of forest resources to maintain an ecological balance, improve productivity, and support economic development. In contrast, responsible wood consumption refers to practices that sustainably promote the use of wood products that minimize environmental impacts and ensure the availability of future generations of resources (Osunyuyi, 2024). According to Janssen and Buhrmann, (2018) a transition to sustainable production and responsible timber consumption is essential, various guidelines and initiatives have been introduced to promote sustainable forest practices, but their implementation often faces challenges due to inadequate enforcement, corruption, and lack of consumer awareness. It is also urgent to revise the socioeconomic aspects of sustainability, particularly the role of communities and industries in forest management (Odebiyi, *et al.,* 2021). This paper intends to provide a comprehensive overview of the state of sustainable wood production and responsible consumption in Nigeria. It also examine current practices in the timber industry, the ecological and economic impacts of non-compliant practices, and the challenges involved in promoting sustainable timber production. Additionally, potential strategies and political recommendations have been considered, which can encourage the transfer to a more sustainable and responsible approach to Nigeria's timber consumption.

The Current State of Wood Production in Nigeria

Overview of the Wood Industry

Nigeria's wood industry is a significant economic sector, contributing to employment, trade, and infrastructure development. The industry is categorized into multiple segments: timber production, plywood, particleboard, and other wood-based products (FAO, 2021). According to recent reports, Nigeria possesses approximately 12 million hectares of industrially managed forests, supporting the timber industry (Forest Research Institute of Nigeria, 2021). Nigeria's wood industry plays a vital role in the national economy, providing raw materials for various industries, including construction, furniture, and paper production. The forestry sector directly employs over 1.2 million people and affects an estimated 30 million individuals (National Bureau of Statistics, 2020). The global wood industry has multiple sectors: logging, sawmilling, plywood manufacturing, and furniture production (Youngquist, 1999).

Wood is essential for construction, packaging, and paper production, contributing significantly to economic growth and employment worldwide (FAO, 2015). However, sustainability challenges such as deforestation, inefficient utilization, and excessive waste generation necessitate innovative management strategies (Nwobodo, 2020). However, the industry faces considerable challenges such as deforestation, illegal logging, and inefficient processing techniques that threaten the sustainability of wood production (Ogunjinmi *et al.,* 2020). The country relies heavily on tropical hardwood species, with states such as Ondo, Ogun, and Cross River serving as major wood-producing regions (FAO, 2021). Despite the abundance of forest resources, poor management and weak enforcement of sustainable practices have led to resource depletion. Furthermore, outdated processing technologies contribute to high levels of waste generation (Ajayi and Adeyemi, 2020). Developed nations have implemented advanced technologies such as engineered wood, reforestation programs, and circular economy principles to enhance sustainability (Wolff and Schweinle, 2022). In contrast, many developing countries, including Nigeria, struggle with issues of illegal logging and unsustainable forest management practices, highlighting the urgent need for policy reforms and industry improvements (Sola *et al.*, 2020). To address these concerns, Nigeria has initiated afforestation programs and promoted the adoption of alternative wood products, such as engineered wood and bamboo-based materials.

Current Challenges in Wood Production

Despite its economic importance, the wood production sector in Nigeria faces several challenges and these are;

i. **Deforestation and Degradation**: Unsustainable logging practices, agricultural encroachment, and urbanization have led to significant forest loss. Reports indicate that Nigeria

loses approximately 4.2% of its forest cover annually, primarily due to illegal logging and land conversion for agriculture (Global Forest Watch, 2020).

ii. **Illegal Logging**: The prevalence of illegal logging activities undermines efforts for sustainable forest management. The World Bank (2018) estimates illegal logging accounts for up to 70% of timber production in Nigeria, leading to significant economic losses and forest degradation.

iii. **Policy and Regulatory Framework**: Nigeria has laws governing forest management, enforcement remains weak, corrupted, lack of transparency, and inadequate resources for monitoring compliance hinder effective implementation of forestry policies (Ogunleye, 2019).

iv. **Economic Pressure**: The high demand for wood products, driven by domestic consumption and international trade, places considerable pressure on Nigeria's forest resources (Ogbiuigwe, 2018). This economic pressure often leads to prioritization of short-term gains over sustainable practices.

Initiatives for Sustainable Wood Production

Several initiatives are being undertaken in Nigeria to promote sustainable wood production. They includes the following the followings;

i. **Certification Programs**: Organizations like the Forest Stewardship Council (FSC) are working to establish certification programs that encourage responsible forestry practices (Nduka *et al.,* 2021). Certified timber is increasingly favoured in international markets, providing an incentive for sustainable practices.

ii. **Reforestation Efforts**: Various Non-Governmental Organizations (NGOs) and government bodies are engaged in reforestation programs aimed at restoring degraded forests and improving forest cover (Nwankwo *et al.,* 2021).

iii. **Public Awareness Campaigns**: Awareness campaigns are being launched to educate consumers and producers

Plate 1: Deforestation, wood exportation impact on furniture business in Nigeria

Source: Ogunjinmi, *et al* (2020)

3. Impacts of Unsustainable Wood Production

Unsustainable wood production practices pose significant environmental, social, and economic challenges, particularly in a biodiversity-rich country like Nigeria (He and Turner, 2022). The negative consequences of such practices can be categorized into several key areas such as;

Environmental Impacts

a. **Deforestation**: Unsustainable logging contributes to significant deforestation, which is the permanent removal of forests to make way for agricultural activities, urbanization, or logging itself (Adeleke and Olaniyan, 2021). Nigeria has one of the highest deforestation rates in the world, with an estimated loss of about 4.2% of forest cover annually (Global Forest Watch, 2020). This loss diminishes biodiversity and disrupts ecosystems that rely on forest habitats.

b. **Loss of Biodiversity**: Forests are home to a vast array of plant and animal species. Unsustainable logging practices lead to habitat destruction, threatening many species with extinction. In Nigeria, unique flora and fauna are at risk due to habitat loss, which has implications for ecological balance and the provision of ecosystem services (Adebayo, 2020).

c. **Soil Erosion**: The removal of trees leads to soil degradation and increased erosion. Without tree roots to stabilize the soil, heavy rains can wash away nutrient-rich topsoil, rendering the land less fertile for agriculture and increasing sedimentation in waterways (Ogunjinmi, 2019).

d. **Climate Change**: Forests act as carbon sinks, absorbing carbon dioxide from the atmosphere. Unsustainable wood production releases stored carbon back into the atmosphere, exacerbating climate change. Deforestation is a significant contributor to greenhouse gas emissions globally, accounting for approximately 10-15% of total emissions (IPCC, 2019).

Social Impacts

i. **Displacement of Communities**: Unsustainable wood production often leads to the displacement of indigenous and local communities that depend on forests for their livelihoods. The loss of forest resources undermines their cultural heritage and access to traditional practices (Ogbuigwe, 2018).

ii. **Health Risks**: The environmental degradation resulting from unsustainable logging can lead to various health issues. For instance, loss of tree cover can increase air and water pollution, contributing to respiratory problems and

waterborne diseases among nearby communities (Nwobodo *et al.,* 2019).

iii. **Increased Poverty**: Unsustainable practices can drive communities into poverty by depleting natural resources upon which their livelihoods depend. The degradation of forests reduces the availability of non-timber forest products, which are essential for food security and income generation (Olatunji, 2019).

Economic Impacts

i. **Loss of Revenue**: The illegal logging industry undermines legitimate forestry operations, resulting in lost revenue for the government and legal operators. It is estimated that Nigeria loses billions annually due to illegal logging and the associated impacts on sustainable forestry management (World Bank, 2018).

ii. **Resource Depletion**: Unsustainable practices lead to the depletion of timber resources, resulting in long-term economic losses for the forestry sector. The inability to replenish harvested timber can result in higher costs for future wood procurement and affect the supply chain (Ademola, 2019).

iii. **Decreased Tourism Potential**: Forests are often key attractions for ecotourism, which is an important source of income in many regions (Häberli, 2013).

iv. Unsustainable logging practices diminish the aesthetic and recreational value of forests, negatively influencing tourism (Idris, 2020).

The impacts of unsustainable wood production in Nigeria are profound, affecting environmental integrity, social structures, and economic stability (Holl, 2011). To mitigate these impacts, it is crucial to adopt sustainable forest management practices, promote responsible consumption, and engage local communities in forestry governance.

Plate 2: Loads of timber

Sources: Monguno *et al.*, (2018)

STRATEGIES FOR SUSTAINABLE WOOD PRODUCTION

Sustainable wood production is crucial for balancing ecological integrity, economic viability, and social equity (Lawson and MacFaul, 2014). In Nigeria, forests are under immense pressure from logging, agriculture, and urbanization, implementing effective strategies is essential. Key strategies include Sustainable Forest Management (SFM), Promoting

Agroforestry, Encouraging Reforestation and Afforestation, Promoting Efficient Wood Utilization, Strengthening Policy and Governance, and Investing in Advanced Wood Processing Technologies. Encouraging the use of Non-Timber Forest Products (NTFPs) and recycling wood products can also contribute to sustainable practices (Mastrorillo, 2016). Strengthening legal frameworks, monitoring forest health, and collaborating with stakeholders can further support sustainable wood production in Nigeria.

Responsible Wood Consumption

Responsible wood consumption is crucial for sustainable forestry practices in Nigeria, where the wood industry plays a significant role in the economy (Kokoye, 2017). It involves sourcing wood from sustainable sources, promoting efficient use, and considering the lifecycle impacts of wood products (Bauhus *et al.,* 2017). Promoting responsible wood consumption can help mitigate deforestation, biodiversity conservation, and economic benefits. Strategies for promoting responsible wood consumption include public awareness campaigns, incentives for sustainable practices, collaboration with stakeholders, and promoting alternative materials like bamboo or recycled materials (Burgess, 2015). These efforts can help balance economic growth with environmental sustainability. Sustainable wood consumption is crucial for Nigeria's forest management, biodiversity preservation, and economic stability (GFW, 2020). Technology plays a vital role in enhancing efficiency, reducing environmental impact, and managing forest resources responsibly (Adediran *et al.*, 2016). Precision forestry, sustainable harvesting techniques, biotechnology, and wood processing technologies contribute to sustainable wood production. Sustainable supply chain management, traceability, and education are also essential for sustainable wood production. Collaboration between government, industry, and civil society is necessary to foster a culture of responsible wood consumption.

CONCLUSION AND RECOMMENDATIONS

Conclusion

Sustainable production and responsible wood use in Nigeria are vital to promoting environmental sustainability, economic prosperity, and social fairness. The growing demand for wood products has resulted in unsustainable practices that have caused substantial environmental degradation, such as deforestation, biodiversity loss, and negative effects on local populations. However, sustainable production methods, ethical consumption behaviours, and active community engagement help to ameliorate these issues and foster a more sustainable future. A balance needs to be struck between the environment and human survival because of the rise in mass

unemployment to ensure natural resource sustainability (Ikemefuna *et al.*, 2021). This study emphasised the necessity of combining sustainable forestry methods, technology advancements, and community participation to achieve responsible wood use. This may improve wood output industry while preserving its natural resources by using appropriate forest resource management practices.

Recommendations

1. **Enforce Strict Regulations**
   The Nigerian government should implement and enforce laws on sustainable wood production and responsible consumption to prevent illegal logging and environmental degradation.
2. **Promote Sustainable Forestry Practices**
   Encourage the adoption of best practices in forest management, including afforestation, reforestation, and controlled harvesting techniques.
3. **Encourage Community Engagement**
   Involve local communities in forest conservation and wood production activities through education, incentives, and inclusive decision-making.
4. **Invest in Technological Innovations**
   Support the use of modern, eco-friendly technologies in wood processing and residue management to improve efficiency and reduce environmental impact.
5. **Launch Public Awareness Campaigns**
   Raise public awareness about the importance of sustainable wood use and the environmental consequences of unsustainable practices.
6. **Strengthen Collaborations**
   Foster partnerships among government agencies, NGOs, academic institutions, and the private sector to promote sustainable wood production.
7. **Support Research and Development**
   Fund research initiatives focused on sustainable forestry, alternative materials, and innovative wood utilization methods.
8. **Establish Monitoring and Evaluation Frameworks**
   Develop robust systems to track progress, ensure compliance, and continuously improve policies and practices related to wood production and management.

These strategic actions will contribute to a sustainable wood production industry in Nigeria that balances **environmental preservation**, **economic growth**, and **community development**.

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IDENTIFICATION OF THREATENED AGROFORESTRY PARKLAND TREES IN POTISKUM LOCAL GOVERNMENT AREA, YOBE STATE NIGERIA.

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SUB THEME: INTEGRATING AGROFORESTRY SYSTEMS FOR FOOD SECURITY AND CLIMATE ADAPTATION

ABSTRACT

The study was designed with the aim to assess indigenous knowledge on the threaten tree species on agroforestry parkland in Potiskum Local Government Area, Yobe State Nigeria. Data were obtained on the threatened tree species, benefits of the trees and challenges encountered in the area. Reconnaissance survey was carried out to get acquainted and familiarized with the demographic activities in the area. A multistage sapling procedure was employed to get the study sample size. At first stage, Potiskum L.G.A. was selected purposively because of familiarization in the area. Secondly, three wards (Mamudo, Garin Daye, Ngojin/Alaraba) were purposively selected out of the ten wards based on the agroforestry farmers in the area. A total of forty (40) respondents were conveniently administered randomly from each of the ward selected at the third stage which stood up one hundred and twenty (120) sample size. Results revealed that *Khaya senegalensis, Vitallaria paradoxa, Tamarindus indica* and *Parkia biglobosa* with 55%, 44.2%, 40% and 35% were the most economical species to the respondents and the most threatened tree species in the area.. Findings revealed that majority of the respondents agreed *Moringa oleifera* (drumstick tree) i and *Syzygium cumini* (black plum) is threatened. The study further revealed that *Kalotropia procera* and *Khaya senegalensis* is mainly used for medicinal use. Conclusively, this study revealed that majority of the respondents agreed that human interference is the main challenge facing in managing the species. It is recommended that Government should provide cheap alternative sources of energy to discourage people from using fuel wood as a source of energy which has caused the reduction of forest resources over the years.

INTRODUCTION

The existence of many species worldwide are been threatened by the activities of man and other factors such as urbanization, a surge in the population of human and clear felling of trees for agricultural purposes (Ogundele and Omotayo, 2008; Varshney and Anis 2014). Biodiversity is known to be vital because they influenced the overall health status of the ecosystem (Naidu and Kumar, 2016; Wakawa *et al.,* 2017). Various tree damages caused either natural or by human damages on the tree have been said to affect the growth of the tree and this also affects biological setting and processes within the forest area which has resulted to many endemic trees species now endangered tree species in the forest as asserted by

Stjernquist *et al*., (2002). Local biodiversity loss due to timber extraction can disrupt the long-term resilience of forests, which may in turn lead to an impoverished delivery of ecosystem services, and ultimately affect human well-being (Edwards *et al.,* 2014; Chaudhary *et al.,* 2016; Hooper *et al.,* 2012).

The decline of forest tree species in Potiskum Local Government Area poses a significant environmental challenge. This decline could be primarily attributed to human-induced factors such as deforestation, land-use change, and unsustainable harvesting practices. Deforestation, driven by agricultural expansion and urbanization, results in the loss of forest cover and habitat fragmentation, directly impacting the survival of tree species which without intervention could lead to the extinction of critical tree species within the region. The significance of the study on threatened and endangered forest tree species in Potiskum Local Government Area encompasses several critical aspects, contributing to biodiversity conservation, socio-economic development, and informed policy-making for forest management.

This study was aimed at assessing the indigenous knowledge on the threaten tree species in Potiskum Local Government Area of Yobe State, Nigeria. These were carried out by assessing the socio-demographic characteristics of respondent in the study area, identifying the threatened tree species and describe the perceived challenges faced by the identified species. At the end, the study contributed to biodiversity conservation, socio-economic development, and informed policy-making for forest management, thereby providing valuable information for conservation planning and management. By prioritizing conservation actions for these species, the study helped safeguard the genetic diversity and ecological integrity of the region's forests, ensuring their long-term sustainability. It also provided a baseline for stakeholders at various levels, including government agencies, local communities, NGOs, and researchers, to ensure effective implementation of conservation measures and equitable distribution of benefits.

METHODOLOGY

Study Area

Potiskum Local Government Area (LGA) is situated in the northeastern region of Nigeria, within Yobe State, with latitude 11.7208° N, longitude: 11.0785° E. (google map). The study area is semi-arid environment, characterized by hot and dry conditions for the majority of the year. The region typically has two distinct seasons: a dry season, which lasts from November to March, and a rainy season, which occurs from April to September. The vegetation is Sahel savannah ecological zone characterized with short tree species. The tree species found in the area includes *Fatherbia albida, Acacia* species,

Adansonia digitata, Tamarindus indica, Parkia biglobosa, Vitellaria paradoxa, Hyphaene phebaica during reconnaissance survey.

Sampling Size and sampling Procedure

A reconnaissance survey was carried out in the study area to enable the researcher familiarized with communities participating on assessing the threatened and endangered forest tree species in Potiskum LGA, Yobe State, Nigeria. A multistage sampling procedure was employed to obtain samples of the study. At first stage Potiskum LGA was chosen based on the familiarity and convenience in the area. At the second stage, three wards were selected purposively out of the ten wards based on the familiarization and accessibility to the area. Thirdly, Fourty (40) respondents were conveniently selected randomly from each of the selected wards because of the inadequate information on the population in the areas which stood up at 120 respondents.

LGA Selected	NO. of wards in LGA	Selected Wards	NO. of respondents
		Mamudo	40
Potiskum	10	Garin Daye	40
		Ngojin/Alaraba	40
Total			**120**

Data Collection and Analysis

Both primary and secondary information were used for the data collection. Primary data was used using questionnaire, while secondary information was obtained through internet, journals and related articles. Data collected from field surveys, were retrieved and analyzed using descriptive statistics, percentages and frequency.

RESULTS AND DISCUSSION

Demographic Information of the Respondents

The result in Table 1 showed that 30(25%) of the respondents were within the age of 20 – 30, 60(50%) within the age of 31 – 40, 20(16.6%) were within the age of 41 – 50 and 10 (8.4%) of the respondents were within the age of 51 and above. This shows that majority of the respondents were within the range of 31 – 50 in the study area.

On the age of the respondents, the table showed that 92(76.6%) of the respondents were male and 28(23.4%) were female. This may be attributed to the nature of the area where culture,

norms and values that restricts women from doing some businesses. Marital status showed that 48(40%) of the respondents were single, 62(51.7%) were married, 6(5%) were divorced and 4(3.3%) of the respondents were separated. This implied that majority of the respondents were married. This showed that married people are saddled with the responsibilities on the endangered forest trees species and their benefits in Potiskum Local Government Area. The result revealed that 34(28%) of the respondents were civil servants, 59(50%) were farmers, 18(15%) of the were traders, and others occupied 9(7%). About 27(22.5%) of the respondents attained were primary school, 61(50.8%) had secondary certificate, 18(15%) attended tertiary institution and 14(11.7%) of the respondents were non-formal education. This implied that majority of the farmers were secondary school certificate holders. The table further showed that majority 65(54.2%) of the respondents has household size of 1 – 5 persons, 43(35.8%) had 5 – 10 household size, 10(8.4%) had 10 – 15 household size and 2(1.6%) of the respondents were 15 and above household size. This results is in line with Gupa *et al*. (2024) titiled "role of agroforestry as a strategy for improving livelihood income in Borno State Nigeria".

Table 1: Socio-Demographic Characteristics of the Respondents

Variables	Frequency	Percentage (%)
Age		
20 – 30	30	25
31 – 40	60	50
41 – 50	20	16.6
51 and above	10	8.4
Total	**120**	**100**
Sex		
Male	92	76.6
Female	28	23.4
Total	**120**	**100**
Marital Status		
Single	48	40.0
Married	62	51.7
Divorced	6	5.0
Separated	4	3.3
Total	**120**	**100**
Occupation		
Civil servant	34	28
Farmer	59	50
Trader	18	15
Others	9	7.0
Total	**120**	**100**
Education		
Primary	27	22.5
Secondary	61	50.8
Tertiary	18	15
Non- formal	14	11.7
Total	**120**	**100**
Household size		
1 – 5	65	54.2
5 – 10	43	35.8
10 – 15	10	8.4
15 and above	2	1.6
Total	**120**	**10%**

Source: Field work, 2024

Benefits and Identification of the threatened Tree Species

the benefits of the threatened tree on the agroforestry parkland in the study area is presented in Table 3. It was observed that the threaten tree species in the area provided numerous benefits for the sustainable livelihood improvement. Among the benefits and services identified by the respondents were provision of timer, fuelwood, and used for medicinal purpose, agroforestry, fencing, windbreak and shed among

others. These were corroborated by reports of Karky *et al*., (2019) who reported that forest trees contribute significantly to the economy through various direct and indirect economic activities. The United Nations Framework Convention on Climate Change (UNFCCC, 2021) documented that timber production is one of the primary economic benefits derived from forests, providing raw materials for construction, furniture making, paper production, and other industries. Moreover, non-timber forest products such as fruits, nuts, resins, and medicinal plants are important sources of income for rural communities and indigenous peoples

Table 3: Benefits and Identification of Threatened Tree Species

Species Name	Medicinal	Timber	Fuel	Shed	Agro/f	Windbreak	Fencing	
	Freq./%	Freq./%	Freq./%	Freq./%	Freq./%	Freq./%	Freq./%	Total
Tamarindus indica	53 (44.2%)	10 (8.3%)	5 (4.2%)	7 (5.8%)	32 (26.6%)	9 (7.5%)	4 (3.4%)	120 100%
Adansonia digitata	37 (30.8%)	11 (9.2%)	4 (3.3%)	15 (12.5%	43 35.8%)	5 (4.2%)	5 (4.2%)	120 100%
Parkia biglobosa	42 (35%)	5 (4.2%)	11 (9.2%)	2 (1.6%)	57 (47.5%)	2 (1.6%)	1 (0.9%)	120 100%
Vitellaria paradoxa	48 (40%)	8 (6.6%)	8 (6.6%)	2 (1.8%)	52 (43.4%)	1 (0.8%)	1 (0.8%)	120 100%
Hyphaene thebaica	39 (32.5%)	10 (8.3%)	7 (5.8%)	7 (5.8%)	49 (40.8%)	5 (4.3%)	3 (2.5%)	120 (100%
Vitex doniana	33 (27.7%)	10 (8.3%)	10 (8.3%)	8 (6.6%)	43 (35.8%)	10 (8.3%)	6 (5%)	120 (100%
Azadrachta indica	24 (20%)	11 (9.2%)	48 (40%)	17 (14.2%)	9 (7.4%)	5 (4.2%)	6 (5%)	120 (100%
Prosopis Africana	38 (31.7%)	20 (16.7%)	38 (31.7%)	10 (8.3%)	12 (10%)	2 (1.6%)	0 (0%)	120 (100%
Acacia Senegal	37 (30.8%)	5 (4.2%)	10 (8.4%)	4 (3.4%)	55 (45.8%)	8 (6.6%)	1 (0.8%)	120 (100%
Ziziphus mouritiana	40 (33.3%)	1 (0.8%)	19 (15.8%)	4 (3.3%)	47 (39.3%)	6 (5%)	3 (2.5%)	120 (100%
Acacia seral	8 (6.6%)	1 (0.8%)	63 (52.6%)	4 (3.3%)	41 (34.2%)	3 (2.5%)	0 (0%)	120 (100%
Faidherbia albida	5 (4.2%)	32 (26.7%)	62 (51.7%)	4 (3.3%)	12 (10%)	3 (2.5%)	2 (1.6%)	120 (100%
Vitellaria paradoxa	34 (28.4%)	8 (6.6%)	55 (45.8%)	7 (5.9%)	12 (10%)	3 (2.5%)	1 (0.8%)	120 (100%
Guiiera senegalensis	40 (33.3%)	16 (13.3%)	30 (25%)	9 (7.5%)	15 (12.5%)	9 (7.6%)	1 (0.8%)	120 (100%
Moringa olifera	58 (48.3%)	4 (3.4%)	24 (20%)	4 (3.4%)	27 (22.5%)	1 (0.8%)	2 (1.6%)	120 (100%
Khaya senegalensis	66 (55%)	13 (10.8%)	15 (12.5%)	3 (2.5%)	22 (18.4%)	0 (0%)	1 (0.8%)	120 (100%
Lawsonia inermia	30 (25%)	0 (0%)	17 (14.2%)	11 (9.3%)	20 (16.6%)	5 (4.1%)	37 (30.8%)	120 (100%
Calotropia procera	66 (55%)	10 (8.4%)	20 (16.7%)	0 (0%)	16 (13.3%)	7 (5.8%)	1 (0.8%)	120 (100%
Bombax costatum	30 (25%)	7 (5.8%)	13 (10.8%)	5 (4.3%)	60 (50%)	2 (1.6%)	3 (2.5%)	120 (100%

Source: Field work, 2024

Challenges Facing Managing the Tree Species

The challenges facing tree species mitigation are presented in Table 4. It was observed that 30(25%) of the respondents identified urbanization as the challenged facing in managing tree species, 9(7.5%) said insecurity 19(15.8%) mentioned natural hazard, 6(5%) identified flooding, 10(8.3%) mentioned uncontrolled

hazard as the challenged lead to threatening of tree species. Also 35(3.3%) of the respondents identified human interference as the cause and 4(3.3%) mentioned fire as the challenged facing in managing species. A few 7(5.9%) said that habitat is the challenge facing in managing species. This agreed with Ahmed and Olaitan (2024) which documented that Nigeria is losing steadily economic opulence, leavin her with harzard from erosion,floodind illegly engaged in export of log and get solace in unlawful taxes and illegitimate royalties which fetch them personal income from this repulsive job.

Table 4.4: Challenges facing in managing the species

Items	**Frequency**	**Percentages (%)**
Urbanization	30	25
Insecurity	9	7.5
Natural Hazard	19	15.8
Flooding	6	5.0
Uncontrolled hazard	10	8.3
Human interference	35	29.2
Fire	4	3.3
Habitat	3	2.5
Others	4	3.4
Total	**120**	**100**

Source: Field work, 2024

CONCLUSION AND RECOMMENDATIONS

Conclusion

Based on the findings of this study it was apparent that many tree species in the area were under threaten and some were already endangered. Drumstick tree, black plum were among the threatened and endangered. It is evident from the study that *Calotropia procera* and *Khaya senegalensis* were few among the tree species for medicinal use. Conclusively, this study revealed that majority of the respondents agreed that human interference is the main challenge faced in managing the tree species.

Recommendations

1. With lack of documented forest management plan in the study area, such kind of study need to be documented and be available to the general public, government officials for proper action.
2. Encouragement should be given to private developers of forests and also incentives could be through free seedling distribution and free land holding.
3. Government should provide cheap alternative sources of energy to discourage most Nigerians from using fuel wood as a source of energy which has caused the reduction of forest resources over the years.

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SPATIAL VARIATION AND CORRELATION OF PHYTOCHEMICAL CONSTITUENTS OF AFRICAN LOCUST BEAN TREES (*Parkia biglobosa* Jacq.) IN SABO-GARIN LOCAL GOVERNMENT AREA, KADUNA STATE, NIGERIA.

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ABSTRACT

This study focused on spatial variation and correlation of phytochemical constituents of African locust bean trees in Sabon-Gari Local Government Area, Kaduna State. Samples were collected from three selected locations (Bomo, Kudingi and Sabo-Birnin) and plant part (roots, stem bark and leaves) which were factorially combined in a 3x3 resulting in nine (9) treatments laid out in complete randomized design (CRD) replicated three times, hence, subjected to phytochemical analysis using standard laboratory procedures. Data were collected on alkaloids, tannins, phytates, oxalates, saponins and flavonoids. Phytochemical analysis showed significant variations in bioactive compounds influenced by location and plant part. Significant higher amount of these compounds was recorded in Kudingi than other two locations from stem bark (alkaloid = 1.53mg), leaves (phytates = 0.83mg, oxalates = 0.18mg and saponins = 19.03mg) and roots (tannins = 2.55mg and flavonoids = 91.16mg). Correlation analysis showed strong positive and negative relationships between some of the bioactive compounds (tannin and phytates r = -0.4103, phytates and oxalate r = 0.7019) with respect to spatial variation and plant parts. Therefore, there is need to explore environmental factor responsible for these variations and its implications for sustainable conservation and utilization.

Keywords: ***Parkia biglobosa*, phytochemical, spatial variation, correlation, plant parts**

Introduction

Parkia biglobosa (African Locust bean) is a perennial deciduous tree species which has many uses in Nigeria (Ntui, *et al.,* 2012). It is a multipurpose tree that serves as food, medicinal, cultural, economic and magico-therapeutic purposes, hence it is treated as priority plant resources for future benefit of local communities in Africa and world at large (Koura *et al.,* 2011; Shao, 2002; Ajayi, 2014; Gernah *et al.*, 2007 and Builders *et al.,* 2011). In West Africa, the bark, roots, leaves, flowers, fruit and seeds are commonly used in traditional medicine to treat a wide diversity of complaints both internally and externally; sometimes in combination with other medicinal plants. In the research carried out in healer's conference in Togo*, P. biglobosa* was one of the highest cited plants used for treating hypertension (Oladimeji, *et al.,* 2021).

Traditional knowledge of its medicinal uses is at risk of being lost due to rapid modernization and decline of traditional healers (Nwachukwu *et al.*, 2010). Medicinal plants are known to be rich sources of bioactive compounds that can serve as templates for developing novel therapeutic agents. Previous studies have shown presence of flavonoid, tannin, and saponin that possess antimicrobial, antioxidant, and anti-inflammatory properties (Ajaiyeoba *et al*., 2002). Phytochemical analysis of this plant can uncover specific compounds with significant pharmacological potential. In many rural African communities, *P. biglobosa* is a readily available and affordable source of healthcare. However, scientific validation of its medicinal properties is limited, which is critical in promoting its integration into formal healthcare systems (WHO, 2013).

Locust bean is used in traditional medicines for its potential health benefits, including its antioxidant and anti-inflammatory properties (Ogunjobi *et al.,* 2021). *Parkia* species are being used across all tropical countries to cure different ailments. Virtually, all parts of *Parkia* plants are utilized traditionally for different medicinal purposes. Materials from different parts such as leaves, stem bark and roots are processed as paste, decoction, and juice for treatment of various ailments such as diarrhea, dysentery, diabetes, skin-related diseases, hypertension, severe cough and bronchitis (Araujo *et al*, 1995; Aiyelaagbe, *et al* 1996; Kouadio, *et al*, 2000; Tringali *et al*, 2000; Ajaiyeoba, 2002; Asuzu and Harvey, 2003; Fotie *et al* 2004; Roosita *et al* 2008; Ong *et al* 2011; Singh, 2019). These uses suggested that Parkia plants are likely to contain constituents with broad and diverse biological activities (anti-diabetic, antimicrobial, antihypertensive, and anti-inflammatory).

Several studies have shown that the plant parts are rich in various phytochemicals present in the bark, leaves and roots of the plant (Femi-Ola *et al.* 2008; Alinde *et al* 2014; Bawa-Allah and Akinnouye 2019). These secondary metabolites include saponins (cardioprotective), tannins (reduce serum cholesterol and triglycerides), flavonoids, resins, carbohydrates, terpenoids (antioxidant, anti-hypercholesterolemic and cardioprotective activities), phenols, sterols, isoquinoline alkaloids, indole alkaloids, reducing sugars and cardiac glycosides (cardiotonic agent). In addition, coumarins, anthocyanins and anthracenosides are present in stem bark and leaf of this plant (Millogo-Kone *et al*, 2008), as well as mineral elements such as magnesium, calcium, iron, zinc, potassium, sodium and copper (Builders *et al*, 2012). Long-chain ester of transferulic acid, a mixture of long-chain cisferulates and different kinds of catechins, have been identified in the stem bark of *P. biglobosa* (Tringali *et al*, 2000). The coumarin derivatives in leaf extract have anticoagulant activity while the aglycone flavonoids have spasmolytic activity on smooth muscles, and also vasodilatory and antiseptic effects (Alinde *et al*, 2014).

These bioactive compounds present in different part of the plants varied, and this variation could be influenced by geographical location of where each specific tree is growing under different environmental factors such as rainfall, temperature, relative humidity and soil type found in such area. Hence, this study was conducted to determine effect of spatial variation in location and correlation of phytochemical compounds of *P. biglobosa* from different plant parts.

Materials and Methods

Study Area

The study was conducted 2023 rainy season at three selected locations (Bomo, Kudingi and Sabo-Birnin) in Sabo-Garin Local Government Area, Kaduna State, Nigeria which lies on latitude 11°09'52"-11°10'22" N and longitude 07°38'05"-07°38'22" E at 686m above sea level (NGI, 2024). The selected locations are known for the presence of large number of locust bean tree with high level of trado-medicinal utilization. The area lies in the Northern Guinea Savannah ecological zone with woodland vegetation and underlying grass species (Raji *et al.,* 2004). The climate is characterized by a well-defined dry and wet season, with a mean annual rainfall of 700-1400mm and ambient temperature ranging from 26-32^{0}C. The soil is predominantly loamy, well drained and rich in organic matter. Climatic condition is tropical continental climate also described as tropical savannah. Rainfall duration is about 5months, beginning in May and ending around October after which the dry season begins and ends around May/June (IAR Meteorological unit 2024) .

Experimental Design

The treatment consists of three location (Bomo, Kudingi and Sabo-Birnin) and plant parts (leaves, stem bark and roots). These were factorially combined in a 3x3 to give a total of 9 treatments laid out in a completely randomized design (CRD) replicated 3 times resulting in a total of 27 samples.

Collection and Processing of Plant Materials for Phytochemical Analysis

Parkia biglobosa plant parts samples (roots, stem bark and leaves) were randomly collected from three trees in each location and were bulked together to form composite samples. The samples were air dried under shade for two weeks. The dried sample was chopped into pieces and ground separately to powdered form using blender. The powdered samples were stored in small plastic air-tight containers and labelled according to location and part of plant obtained from. Three replicate each were taken from the prepared samples and subjected to laboratory analysis at Product Development Research Programme, Institute of Agricultural Research, Samaru, Zaria, Nigeria.

Data Collection and Analysis

The plant parts were examined for the presence of alkaloid, tannin, phytate, oxalate, saponin and flavonoid as affected by spatial variation using standard biochemical analysis procedures.

Data collected on bioactive constituents were subjected to analysis of variance (ANOVA) using statistical analysis software (SAS), and mean differences among treatments were separated using Duncan Multiple Range Test (DMRT) at 5% level of probability. Correlation analysis was carried out to determine degree of association between isolated phytochemical constituents with respect to spatial variation and plant parts.

Results and Discussion

Effect of spatial variation and plant part on alkaloid and tannin constituents of *Parkia biglobosa* trees in Sabon Gari local government area

The effect of spatial variation and plant part on alkaloid and tannin constituents of locust bean tree is presented in Table 1

There was significant effect of location and plant parts on alkaloid and tannin constituents of *P. biglobosa*.

The result showed that stem bark from Kudingi resulted in significantly ($P \leq 0.05$) higher amount of alkaloid, while leaves from Sabon-Birnin and Bomo has significantly lower amount of alkaloid. Alkaloids are nitrogen-containing compounds that exhibits diverse pharmacological activities, and are known for their analgesic, anti-inflammatory and antimicrobial properties. Morphine an alkaloid is used as a pain killer, and quinine is used to treat malaria (El-Sayed and Verpoote 2007). Alkaloids also possess anti-cancer and anti-hypertensive effects, making them valuable in drug development. Alkaloid-rich stem bark, such as that of *Cichona* species are renowned for their anti-malarial properties, as they are a source of quinine. (Phillipson and Wright, 1991).

Similarly, result also revealed significant amount of tannin (2.55mg) in roots obtained from Kudingi, while lowest amount was obtained from leaves (0.81mg) at the same location. Tannins are polyphenolic compounds with astringent properties, and they demonstrate antioxidant and antimicrobial activities that helps protect against oxidative stress and bacterial infections (Haslam, 1996). Tannins are also beneficial in wound healing, diarrhea treatment, and managing inflammatory conditions due to their ability to precipitate proteins and form protective barriers. Roots of plants like *Terminalia chebula* have been reported to contain tannins with strong antioxidant and antimicrobial activities (Cheng *et al*., 2003). Tannins in leaves act as protective agents against microbial infections, for example tea leaves (*Camellia sinensis*) are high in tannins, contributing to their antioxidant and antimicrobial effects (Balentine, *et al.*, 1997).

Table 1: Effect of location and plant parts on alkaloid and tannin constituents of *Parkia biglobosa* trees

Location	Plant parts	Alkaloid (mg/100g)	Tannin (mg/100g)
Bomo	Leaf	0.50h ± 0.000	0.91g ± 0.010
	Root	0.76e ± 0.010	1.70c ± 0.000
	Stem bark	1.53b ± 0.025	1.40f ± 0.000
Kudingi	Leaf	0.65f ± 0.005	0.81h ± 0.010
	Root	0.55g ± 0.005	2.55a ± 0.000
	Stem bark	2.00a ± 0.000	1.60d ± 0.000
Sabo-Birnin	Leaf	0.51h ± 0.005	0.90g ± 0.000
	Root	0.88d ± 0.000	1.85b ± 0.000
	Stem bark	1.05c ± 0.050	1.44e ± 0.015
SE±		0.0111	0.0040
Significance		**	**

Means followed by same letter(s) within same column are not different statistically at *P=0.05* level of probability using DMRT
**= F-value significant at (P≤0.01)

Effect of spatial variation and plant part on phytate and oxalate constituents of *Parkia biglobosa* tree in Sabon Gari local government area

The effect of spatial variation and plant part on phytate and oxalate constituents of locust bean tree is presented in Table 2

There was significant effect of location and plant parts on phytate and oxalate constituents of *P. biglobosa*.

Significantly (P≤0.05) high amount of phytate was contained in leaves from Kudingi, while Sabon-Birnin and Bomo contained lowest phytate both in stem bark. Phytates act as natural antioxidant and have potential health benefits, including anti-cancer and cholesterol-lowering effects, though are often criticized for inhibiting mineral absorption, moderate consumption has been linked to reduced risks of cardiovascular diseases and improved glyceamic control (Reddy *et al.,* 1982; Udobi *et al.,* 2008). Phytates in leaves, such as spinach (*Spinacia oleracea*), act as storage molecules for phosphorus and contribute to antioxidant activity (Weaver and Kannan 2001).

The result also shows that Kudingi recorded significantly (P≤0.05) higher amount of oxalate in leaves than other location in all plant parts, while lowest amount of oxalate was obtained from Sabon-Birnin and Bomo from the stem bark. Oxalates found in various plants, can act as chelating agents for heavy metals, potentially aiding in detoxification (Rahman and Kawamura, 2011). However, their excessive intake is associated with kidney stone formation, necessitating balanced consumption for medicinal benefits. Oxalate are typically concentrated in leaves of plants like *Amaranthus* and *Spinacia oleracea*, where they may pose a risk of kidney stone formation but also aid in metal chelation (Noonan and Savage 1999).

Table 2: Effect of location and plant parts on phytate and oxalate constituents of *Parkia biglobosa* trees

Location	Plant parts	Phytate (mg/100g)	Oxalate (mg/100g)
Bomo	Leaf	0.14c ± 0.000	0.15d ± 0.005
	Root	0.14c ± 0.000	0.16c ± 0.000
	Stem bark	0.11d ± 0.000	0.13f ± 0.000
Kudingi	Leaf	0.83a ± 0.025	0.18a ± 0.000
	Root	0.16b ± 0.000	0.14e ± 0.000
	Stem bark	0.14c ± 0.000	0.17b ± 0.005
Sabo-Birnin	Leaf	0.14c ± 0.000	0.14e ± 0.000
	Root	0.14c ± 0.000	0.15d ± 0.000
	Stem bark	0.12d ± 0.000	0.13f ± 0.010
SE±		0.0049	0.0024
Significance		**	**

Means followed by same letter(s) within same column are not different statistically at *P=0.05* level of probability using DMRT
**= F-value significant at (P≤0.01)

Effect of spatial variation and plant part on saponin and flavonoid constituents of *Parkia biglobosa* tree in Sabon Gari local government area

The effect of spatial variation and plant part on saponin and flavonoid constituents of locust bean tree is presented in Table 3

There was significant effect of location and plant parts on saponin and flavonoid constituents of *P. biglobosa*.

The result shows that Kudingi recorded significantly (P≤0.05) higher amount of saponin in leaves than other location, while lowest saponin was contained in roots obtained from Sabo-Birnin. Saponins are glycosides with surfactant properties, contributing their roles in immune modulation, cholesterol regulation, and anti-cancer activity, thereby enhancing the immune response and exhibit cytotoxic effects against tumour cells, making them important in the prevention and treatment of cancer (Francis *et al*., 2002). Saponins in leaves, such as in *Moringa oleifera*, exhibit immune-boosting and anti-inflammatory activities (Anwar *et al*., 2007). Roots of *Glycyrrhiza glabra* (licorice) contain saponins with notable expectorant and anti-ulcerative properties (Asl-Marjan and Hosseinzadeh 2008).

However, the amount of flavonoid obtained from samples shows that Sabon-Birnin produced significantly (P≤0.05) higher flavonoid in roots than other location, while lowest amount was contained in leaves from Kudingi. Flavonoids are polyphenolic compounds with potent antioxidant properties, protecting cells from oxidative damage and reducing risk of chronic diseases like cardiovascular disorders, diabetes and cancer, and their anti-inflammatory and neuroprotective effects make them beneficial in managing neuro-degenerative conditions and inflammatory diseases (Middleton *et al.*, 2000). Roots of plants like *Scutellaria baicalensis*

contain flavonoids like baicalin, known for their anti-inflammatory and hepato-protective effects (Shang *et al*., 2010). Leaves are a significant source of flavonoids, such as quercetin in onions and rutin in citrus plants, offering antioxidant and anti-inflammatory benefits (Middleton *et al*., 2000).

Table 3: Effect of location and plant parts on saponin and flavonoid constituents of *Parkia biglobosa* trees

Location	Plant parts	Saponin (mg/100g)	Flavonoid (mg/100g)
Bomo	Leaf	17.25d ± 0.000	83.45g ± 0.000
	Root	15.25h ± 0.250	84.67e ± 0.000
	Stem bark	16.03f ± 0.025	85.13d ± 0.125
Kudingi	Leaf	19.03a ± 0.025	80.17i ± 0.170
	Root	15.75g ± 0.250	91.16a ± 0.000
	Stem bark	16.73e ± 0.025	85.50c ± 0.000
Sabo-Birnin	Leaf	18.50b ± 0.000	81.84h ± 0.000
	Root	12.40i ± 0.400	89.08b ± 0.075
	Stem bark	18.15c ± 0.150	84.14f ± 0.100
SE±		0.1070	0.0473
Significance		**	**

Means followed by same letter(s) within same column are not different statistically at *P=0.05* level of probability using DMRT
**= F-value significant at (P≤0.01)

Correlation matrix of phytochemical constituents of *Parkia biglobosa* as affected by locations and plant parts

Correlation analysis of phytochemical constituents of *P. biglobosa* as affected by location and plant part is presented in Table 4

There correlation between alkaloid compared to tannin (r = 0.1269), phytate (r = -0.2348), oxalate (r= 0.0301), saponin (r = -0.1149) and flavonoid (r = 0.1399) were positive and negative but very weak. However, tannin shows strong and negative correlations compared to phytate (r = -0.4103) and saponin (-0.6219), strong and positively related to flavonoid (r = 0.5819), but weak and negatively related to oxalate (r = -0.2069). The relationship between phytate and oxalate (r = 0.7019) was strong and positive, while it has weak and positive relationship compared to saponin (r = 0.2782), but strong and negatively related to flavonoid (r = -0.5184). The degree of association between oxalate in relation to saponin (r = -0.0398) and flavonoid (r = -0.1180) were weak and negative. However, the relationship between saponin and flavonoid (r = -0.8933) was strong and negative. The observed strong positive and negative relationships among the phytochemical constituents is an indication of strong interactions indicating a potential mutual and antagonistic relationship in their production and accumulation, while weak, positive and negative relationship indicates no mutual relationship in

their synthesis. The variation in correlation coefficients shows that concentration and synthesis of the phytochemicals are strongly influenced by locations and plant parts. Strong and positively related constituents indicate similar shared pathways or accumulation, while strong negative correlations indicate antagonistic relationships between phytochemical constituents highlighting trade-offs in their synthesis.

Table 4: Correlation matrix of phytochemical constituents of *P. biglobosa* as affected by location and plant part

Var	1	2	3	4	5	6
1	1.0000					
2	0.1269^{NS}	1.0000				
3	-0.2348^{NS}	-0.4103*	1.0000			
4	0.0301^{NS}	-0.2069^{NS}	0.7019**	1.0000		
5	-0.1149^{NS}	-0.6219**	0.2782^{NS}	-0.0398^{NS}	1.0000	
6	0.1399^{NS}	0.5819**	-0.5184**	-0.1180^{NS}	-0.8933**	1.0000

1 = Alkaloid 3 = Phytate 5 = Saponin NS = r-value not significant
2 = Tannin 4 = Oxalate 6 = Flavonoid *= r-value significant at ($P \leq 0.05$)
**= r-value significant at ($P \leq 0.01$) N = 27 DF = N-2 = 25

Conclusion and Recommendation

The results of this study show significant spatial variation of phytochemical constituents of *Parkia biglobosa* of the various plant parts in the study areas. The findings of this study showed higher amount of the phytochemical active compounds were contained in samples obtained from Kudingi than other location. Similarly, out of six bioactive compounds assayed during the study, three were actively higher in leaf samples (phytate, oxalate and saponin), while stem bark contained higher amount of alkaloid and root samples from the same location contained higher amount of tannin and flavonoid. Correlation analysis showed significant relationships between some of the bioactive compounds with respect to spatial variation and plant parts. Hence, there is need to explore environmental factors that influence concentration of these bioactive compounds in the various plant parts which will provide valuable insight into its adaptation and utilization. Therefore, in order to optimize its benefits, there is need for sustainable management practices and further research into its pharmacological applications.

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ANALYSIS OF SAWN WOOD MARKET STRUCTURE IN BENUE STATE, NIGERIA.

Sub-theme: INNOVATIVE UTILIZATION OF WOOD AND FOREST PRODUCTS FOR SUSTAINABLE DEVELOPMENT

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ABSTRACT

The paper analysed the structure of sawn wood markets in Benue State, Nigeria. A multi stage sampling technique was used to select respondents. A total of 100 sawn wood marketers from five Local Government Areas (LGAs) in the State were selected and sampled. Copies of semi-structured questionnaire were used to elicit data from the respondents. The timber market structure in the State was analyzed using concentration ratios such as Lorenz Curve (LC) and Gini Coefficient (GC). The analysis of the distribution of the sales income of sawn wood marketers in Benue State revealed a GC of 0.26. This implied that there was a low degree of inequality among the sawn wood market actors in the State, and therefore, the market structure, though oligopoly, tilted towards competition. The Lorenz curve for the income distribution of sawn wood marketers in the State showed a little departure from the 45^0 line and this is in line with the GC of 0.26. This implied a low variation in incomes and sales distribution of sawn wood marketers in the State. A summary of the sawn wood market structure in Benue State revealed many small scale buyers and sellers, homogenous and substitutable products, competition in the marketing of products, freedom of entry and exit and effective information transmission medium.

Key words: Sawn wood, Markets, Marketers, Sales income, Structure

INTRODUCTION

Sawn wood marketing involves the exchange between a wood buyer and a seller at a given price for profit maximization (Ohwo and Adeyemi, 2015). It entails the sum total of business activities involved in the production and movement of sawn wood from point of production to the consumers (Bauer and Yameh, 1993). In Nigeria, sawn woods are marketed locally in sawmills and wood sheds, with sawmills accounting for about 93.32% of total number of wood-based industries in Nigeria (Fuwape, 2001). Reports have shown that sawn wood marketing contributes to livelihoods in Nigeria (Sekumande and Oluwatayo, 2011) and globally (Giliba, 2010).

Market structure refers to certain characteristics of the market, which are believed to influence the nature of competition and the process of price formation. These characteristics according to Adegeye and Dittoh (1985) include: size and number of buyers and sellers ensuring adequate

intensity of price and quality competition; freedom of entry and exit and the extent of product differentiation (Ebe, 2007; Kotler *et al*., 2007). The major characteristics that economists have focused on in describing the market structure are the nature of competition and the mode of pricing in that market. The market structure will affect how firms price their products in the industry. For example, in a competitive market, the firms are price takers, while the monopoly industry has the sole duty of price setting. A market structure will affect the supply of different commodities in the market and affect the barrier to entry for companies that intend to join that market. According to Sambe *et al*. (2016), market structure defines the marketing system of different types of enterprises, their behaviour and the relationships, as well as the relationship among various sellers and buyers, and between buyers and sellers. The structure of the forest produce market in Nigeria is monopolistic, implying the existence of one major supplier (government) and many buyers. In an ideal economic situation, the market structure of timber markets should have profound implications on the prices and by extension on the conduct and performance of the market (Popoola, 1998). The structure of forest product market, as it is presently, is bereft of good performance. According to Popoola (1998), structural and institutional weaknesses exist in the Nigerian market, hence the failure of the market to operate effectively. This study, therefore, aims to analyse the current structure of sawn wood markets in Benue State.

METHODOLOGY

Study Area

The study was carried out in Benue State, Nigeria, located in the North-Central region of Nigeria. Benue State is bounded in the South-West by Cross-River State, Enugu State and Ebonyi State: in the South-East by the Republic of Cameroon: in the West by Kogi State and in the North-East and East by Taraba State. The State has three agro-ecological zones, namely; the Derived Savanna, the Guinea Savanna and the Lowland Rainforest (Keay, 1949). It lies between latitude $6^0 25'$ and $8^0 8'$N and longitude $7^0 47'$E and 10^0E and has an area of 30,910 km^2 (FORMECU, 1998). According to the result of the 2006 National census, Benue State has a total population of 4,219,244 as against 2,780,398 in 1991 (NPC, 2006). The population of the State was projected to 5,741,800 at 3% annual growth rate in 2016 and projected to 6,141,300 at 2.3% annual growth rate in 2022, with a population density of 199.5/km^2. The State has a total of 23 Local Government Areas (LGAs) which are divided into three geo-political zones. The zones are: Zone 'A' comprising Ukum, Katsina-ala, Logo, Vandeikya, Ushongu, Konshisha and Kwande LGAs. Zone 'B'comprising Gboko, Tarka, Guma, Makurdi, Buruku, Gwer and Gwer-west L.G.As. Zone 'C' comprising Ado, Agatu, Apa, Ohimini, Ogbadibo, Okpokwu, Otukpo, Oju and Obi LGAs. Benue State has a

tropical sub-humid climate, with two distinct seasons, namely; a wet season and a dry season. Open woodland with tall grasses (1-3m high) and trees (up to 15m high) characterize the vegetation of Benue State. The trees are mostly savanna and deciduous trees with short boles, thick barks and broad leaves.

Sampling Technique and Sample Size

A multi stage sampling technique was adopted for the selection of the respondents. The first stage involved the purposive selection of five LGAs with the largest sawn wood markets and marketers in the State. The LGAs selected are; Makurdi, Gboko, Otukpo, Okpokwu and Katsina-ala. The LGAs were selected because of their spatial distribution, market sizes, relative abundance of sawn wood marketers and availability of sawn wood species in them. A total of 100 sawn wood marketers were randomly selected from the timber markets in the LGAs as respondents. One hundred (100) copies of Semi-structured questionnaire were used as the main instrument of data collection. Data collected included, among others, those on the distribution of the marketers' sales income, ease of entry and exit into the market, the number and relative size of buyers and sellers, the degree of product differentiation and the status of knowledge about costs and prices. Other data collected included information on the method of price determination, existence of traders association, membership of association, activities of the association, benefits derived from the association, method of product advertisement/promotion, sources and knowledge of market information, sources of start-up capital and entry barriers.

Data analysis

Determination of Sawn Wood Market Structure

Market structure was analyzed using concentration ratios such as Lorenz curve and Gini coefficient. An important variable in market analysis is concentration, which explains which segment of the market possesses the largest share of the market or business. In this study, the concentration of timber marketers was determined by means of Gini-Coefficient (GC) and the accompanying Lorenz curve. The Lorenz curve is a graph used in economics to show income distribution or spread. The Lorenz curve is obtained by plotting the cumulative proportions of sellers, from the smallest to the largest, against their cumulative sales. In this curve, the cumulative percentage of the sellers was plotted on the X-axis, while their respective cumulative percentage of income was on the Y-axis. These were then joined to produce the Lorenz curve. The line of equal distribution (LED) or the egalitarian line is a straight line from the origin. It is 45^0 to the origin. If the distribution of sales/ income is completely equitable, the curve will pass through the 45 degree line. The greater the inequality, the greater the deviation from the 45 degree line.

Gini Coefficient (GC) was determined from the Lorenz curve as the ratio of the area above the Lorenz curve to the sum of the area above and below the curve as shown below

$$GC = \frac{A}{A+B}$$

Where

GC= Gini coefficient

A= proportion of the population above Lorenz curve

B= proportion of the population below Lorenz curve

GC=0 implies perfect equality

GC=1 implies perfect inequality

GC=0<1 implies a degree of inequality

GC was used to examine the distribution of sales income of sawn wood marketers, which is a reflection of the market structure in the study area. The GC varies from 0 to 1, where 0 implies perfect equality in the distribution (perfect market) and 1 implies perfect inequality (imperfect market). The closer the GC is to zero, the greater the degree of equality in sales income/volume, the lower the level of concentration and the more competitive the markets are. Similarly, as the Gini coefficient approaches unity, the greater the degree of inequality, the higher the level of concentration, the more imperfect the markets are and, consequently, the lower the efficiency of such markets.

RESULT

Structure of sawn wood markets in Benue State

The result of the structure of sawn wood market in Benue State as revealed by the estimate of Gini Coefficient is presented in Table 1.

Table 1: Gini Coefficient Estimation of Income Disparity of Sawn Wood Marketers in Benue State

	1	2	3	4	5= 1x2	6	7	8	9= 3x8
Monthly Income	Mid-Point	Freq. of Traders	% Traders	Cumulative % Traders	Total Income	% Total Income	Cumulative % Total Income	Paired Sum	Trapezoidal Area
<20,000	15000	10	8.26	8.26	150000	1.92	1.92	1.92	15.87
20000-30000	25000	18	14.88	23.14	450000	5.76	7.68	9.6	142.81
30000-40000	35000	4	3.31	26.45	140000	1.79	9.47	17.15	56.69
40000-50000	45000	10	8.26	34.71	450000	5.76	15.23	24.7	204.13
50000-60000	55000	11	9.09	43.8	605000	7.74	22.97	38.2	347.27
60000-70000	65000	5	4.13	47.93	325000	4.16	27.13	50.1	207.02
70000-80000	75000	4	3.31	51.24	300000	3.84	30.97	58.1	192.07

80000-90000	85000	37	30.58	81.82	314500	40.24	71.21	102.18	3124.51
90000-100000	95000	6	4.96	86.78	570000	7.29	78.5	149.71	742.36
100000 above	105000	16	13.22	100	168000	21.50	100	178.5	2360.33
Total	-	121**	100		7815.00	100			7393.07

** Multi-choice responses by respondents, therefore total frequency is higher than total number of respondents

Source: field survey 2021

Estimation of Gini Coefficient

Gini Coefficient (GC) is expressed as:

$$GC = \frac{10{,}000 - \text{Trapezoidal Area}}{10{,}000}$$

$$GC = \frac{10{,}000 - 7393.07}{10{,}000}$$

$$GC = \frac{2606.93}{10{,}000}$$

GC = 0.26

The analysis of the sales income of sawn wood marketers in Benue State revealed a GC of 0.26. In absolute terms, this implies that there is a low degree of inequality among the sawn wood market actors in Benue State, and therefore, market though oligopoly, tilted towards competition. This is in agreement with Sambe *et al*. (2016), who reported that the overall structure of timber markets in Benue State indicated that there were many small-scale dealers such that none could control the market. This type of market structure is competitive because the individual dealers had little influence on the market prices. Generally, the following factors of workable competition characterized the sawn wood market in Benue State. They included: adequate number of buyers and sellers, freedom of entry into the market by new participants, absence of collusion and persistent price discrimination.

The operations of timber markets in Benue State were de-regulatory. Government's involvement in terms of price control boards, subsidies and loans were completely absent. The sector is left in the hands of sawn wood marketers and the buying public. Naturally, the absence of regulatory bodies pre-supposes that the forces of demand and supply of sawn wood products in the market should be effectively competitive. Following Sosnick (1968), as mentioned by Tee (2007), a market is effectively competitive if and only if it is free from two kinds of flaws. These are: conditions that are considered undesirable both in them and in their effects, and conditions that are considered undesirable only because of their effects. The first conditions comprise unfair tactics, and irrationality as depicted by self-defeating choices by buyers and sellers. Unfair tactics include malicious interference with competition, fraud against customers or suppliers, sale of inherently bad products without notice. The second condition comprises inadequate research, undesirable discrimination and undesirable collaboration, predation, pre-emption and refusals to deal. In view of these, sawn wood markets in Benue State could not be said to be perfectly or effectively competitive, because it was not free from such flaws.

Competitors employed different tactics to ensure they acquired large share of the market. Some also engaged in malicious practices such as selling wood at dimensions less than the standard market dimensions to unsuspecting customers. Furthermore, there were no persons employed by the buyers to seek ways of improving products quality and reducing costs. There were also clear cases of collaboration since marketing associations were in existence in all the timber markets in the State.

Lorenz Curve for Income Distribution of Sawn wood Marketers in Benue State

The Lorenz curve relating the cumulative proportion of total sales and the cumulative proportion of sawn wood marketers in Benue State is as shown in Figure 1.

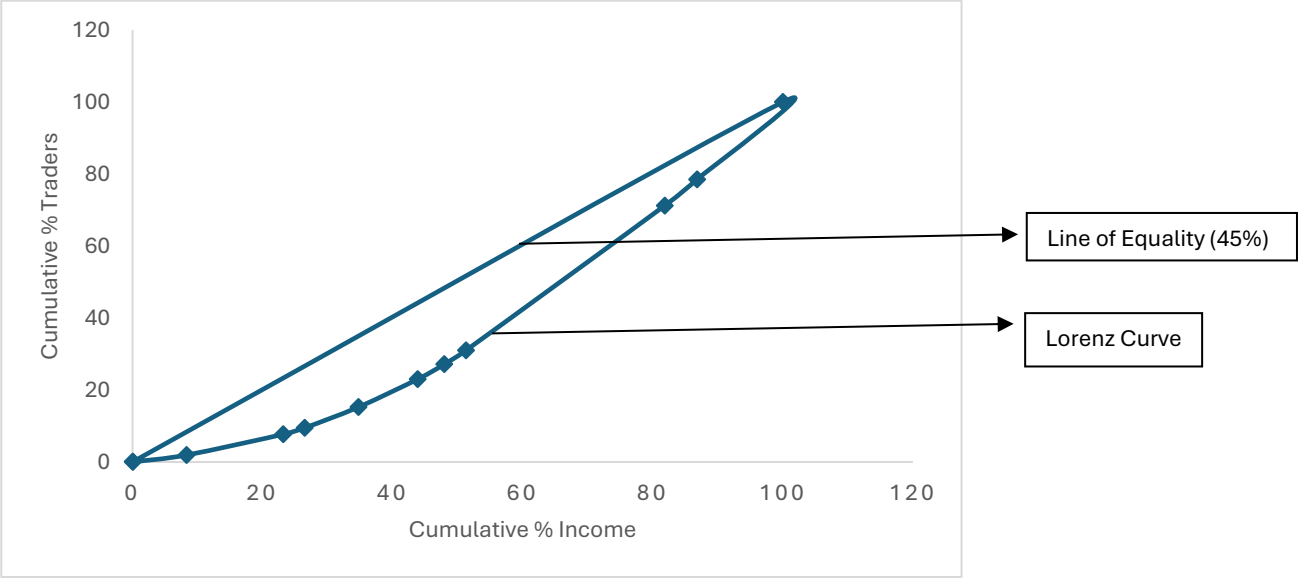

Figure 1: Lorenz curve of income disparity of sawn wood marketers in Benue State

The Lorenz curve for the income distribution of sawn wood marketers in Benue State showed a little departure from the 45^0 line and this is in line with the GC of 0.26. This implied a low variation in incomes and sales distribution of sawn wood marketers in Benue State. It also showed a low market concentration of timber traders, which implied a fairly equitable distribution of marketing agents in the State.

A summary of the sawn wood market structure in Benue State revealed that:

- There were many small scale buyers and sellers, few of which are large enough to wield price settings and volumes of trade
- There was competition in the marketing of products.
- Most products were homogenous and substitutable.

- There were no barriers to entry into the market or exit. Every marketer had freedom of entry and exit once the minimum condition of registration is fulfilled.
- The information transmission medium was effective. It was majorly achieved through their market associations/unions.

Based on the theoretical models of market structure propounded by Bain (1972), and Adegeye and Dittoh (1985), the aforementioned features indicated that the market structure studied was oligopolistic i.e. few sellers and many buyers. This finding corroborates with the report of Popoola (1998), Idoko (2007) and Sambe (2016) on sawn wood markets in Benue State.

CONCLUSION

There was a low degree of inequality among the sawn wood market actors in Benue State. Although the market structure could be described as oligopoly, it tilted towards competition. There was also a low variation in incomes and sales distribution of sawn wood marketers in the State. The market structure in the State revealed many small scale buyers and sellers, homogenous and substitutable products, competition in the marketing of products, freedom of entry and exit and effective information transmission medium. The structure of sawn wood markets affects the pricing and marketing of the product. This happens mostly through market competition. Improved market structure will ensure an efficient marketing system that is highly competitive. Such competitions will help reduce or stabilize the prices of sawn wood and improve its marketing efficiency. Improved structure of sawn wood markets is, therefore, a pre-requisite for efficient sawn wood marketing and sustainable profit making in the sawn wood trade in Benue State. An efficient sawn wood marketing system has potentials of creating a vibrant economy with economic activities that are lively and capable of engendering socio-economic welfare and industrial development. Through efficient marketing, the connection of production and consumption of sawn wood, which are far apart in the State, will be ensured. There is, therefore, the need for effective communication and collaboration among stakeholders, including producers, traders, and consumers for a well-functioning and efficient sawn wood markets. There is also the need for appropriate policies that will ensure constant regeneration and sustainable management of the forests in the State. Loan facilities and basic amenities such as toilets, water and electricity should be provided for the marketers. Policies that will lead to a reduction in the prices of petroleum products should be implemented. Infrastructures such as roads, electricity, communication network etc should be improved both within and outside the markets. Most of all, the security of the forests, lives and properties should be guaranteed to ensure continuous and regular supply of sawn

wood products to the markets, so as to meet the ever increasing demand for sawn wood both within and outside Benue State.

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Title: Trend in Marketed Sawn Wood Species and Dimensions between 2007 and 2021 in Benue State, Nigeria.

Sub-theme: INNOVATIVE UTILIZATION OF WOOD AND FOREST PRODUCTS FOR SUSTAINABLE DEVELOPMENT

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Abstract

The paper identified the most marketed sawn wood species and dimensions in Benue State. Five Local Government Areas (LGAs) were purposively selected for this study. A sampling intensity of 38.6% was used to randomly select a sample size of one hundred (100) out of the total population of two hundred and fifty-nine (259) sawn wood marketers in the selected LGAs. Copies of semi-structured questionnaires were used for data collection. Descriptive statistics were used to compile the most marketed sawn wood species and dimensions in the State. The result indicated that the most marketed sawn wood species between 2007 and 2021 in the State included *D. oliveri* (Agba*), G. aborea* (Malina)*, K. ivorensis* (Mahogany)*, C. petandra* (Akpu)*, A. djalonensis* (Odrobu)*, P. biglobosa* (Nune), *A. leocarpus* (Maaki)*, T. grandis* (Teak) and *M. excelsa* (Iroko). Similarly, the most common dimensions included 2 in. x 12 in. x 12 ft., 1 in. x 12 in. x 12 ft. (plank), 1 in. x 6 in. x 12 ft. (half plank), 2 in. x 2 in. x 12 ft., 2 in. x 3 in. x 12 ft., 2 in. x 4 in. x 12 ft. and 2 in. x 4 in. x 18 ft. (over-length). Of these dimensions, the 1 in. x 12 in. x 12 ft. (plank), with a 30.4% sales rate, was the most marketed because of its diverse uses, while the least marketed is the 2 in. x 12 in. x 12 ft. with 1.7% sales rate.

Keywords: Markets, sawn wood, dimensions

INTRODUCTION

Nigerian forests support a wide range of forest industries, both the formal and informal sub-sectors, which a vast majority of the Nigerian populace depends on for their livelihood (FAO, 2009; Akpabio *et al*., 2013). Forests have been a major contributor to the National Gross Domestic Product (GDP) (Ofoegbu, 2014). According to Ogunwusi (2012), **t**he forest products industry in Nigeria was one of the most developed within the Nigerian economy from the 1960‘s to the early 1970‘s. The wood-base industry is, therefore, very important to the Nigerian economy. FAO (2018) reported that forests and trees supply hundreds of millions of people with food, energy, and income, and act as a safety net during hard times. These people get engaged in activities such as furniture making from sawn wood, rattan and bamboo, charcoal production, collection and processing of non-timber forest products such as medicinal plants, fruits and ropes, fuel wood gathering, honey production, silkworm production, mushroom cultivation, domestication of wildlife for bush

meat; all of these activities are either solely or somewhat forest-based. Throughout history, people relied on wood for needs varying from farming tools to building materials; from fuel to weapons of hunting and warfare; from the first resting place (the baby court) to the final resting place (the coffin) (Fuwape, 2001). Wood remained virtually the most predominant material used for construction and energy generation until the last half of the 19th century (Douglas 1995). In contemporary times, wood is still widely used for construction purposes. Wood that is used as timber, fuel wood, pulp and paper is the most precious and marketable product obtained from most forests (Adedokun *et al*., 2017).

Timber is a major forest product all over the world and it serves as a raw material for wood-based industries. It can be processed in a variety of forms and sizes (Alika, 2005; Barker, 1981), which accounts for many products such as sawn wood, veneer sheets, fibre board, plywood and poles. According to the FAO (1999), sawn wood is the most produced and demanded among other semi-processed and processed wood categories and is the most distributed for construction purposes in Nigeria. It is a regular component/raw material for the socio-economic development of any country. It is very important to the Nigerian economy, as it is used in a variety of ways. Sawn wood processing and marketing contribute to sustainable livelihoods in both rural and urban parts of Nigeria through employment and income generation (Ohwo *et al*., 2014). Sawn wood marketing, like every other marketing enterprise, involves the exchange between a sawn wood buyer and a sawn wood seller at a given price (FAO, 1995; Wollenberg, 2002; Fuwape, 2005). The price is such that the seller meets the total cost as well as the profit margin. Hence, it is the total of all business activities involved in the movement of commodities from the point of production to the point the commodities are received by the ultimate consumers (Barker, 1981; Olukosi and Isitor, 1990). The efficiency of the sawn wood marketing process, as a link between the producer and the consumer, is a major determinant of economic incentives of the forestry sub-sector and this affects the consumption pattern of sawn wood. This paper takes a look at the most marketed sawn wood species and dimensions between 2007 and 2021 in Benue State, Nigeria.

METHODOLOGY

Study Area

The study was carried out in Benue State, Nigeria. Benue State is located in the North central region of Nigeria. It is bounded in the Southwest by Cross River State, Enugu State and Ebonyi State: in the Southeast by the Republic of Cameroon: in the West by Kogi State and in the Northeast and East by Taraba State. The State has three agro-ecological zones, namely; the Derived Savanna, the Guinea Savanna and the Lowland Rainforest (Keay, 1949). It lies between latitude $6^0 25'$ and $8^0 8'$N and longitude $7^0 47'$E and 10^0E and has an area of 30,910 km^2 (FORMECU, 1998). According to the result of the

2006 National census, Benue State has a total population of 4,219,244 as against 2,780,398 in 1991 (NPC, 2006). The population of the State was projected to be 5,741,800 at a 3% annual growth rate in 2016 and projected to be 6,141,300 at a 2.3% annual growth rate in 2022, with a population density of 199.5/ km^2. The State has a total of 23 Local Government Areas (LGAs) which are divided into three geo-political zones. The zones are: Zone 'A' comprising Ukum, Katsina-ala, Logo, Vandeikya, Ushongu, Konshisha and Kwande LGAs. Zone 'B'comprising Gboko, Tarka, Guma, Makurdi, Buruku, Gwer and Gwer-west LGAs. Zone 'C' comprising Ado, Agatu, Apa, Ohimini, Ogbadibo, Okpokwu, Otukpo, Oju and Obi LGAs. Benue State has a tropical sub-humid climate, with two distinct seasons, namely; a wet season and a dry season. Open woodland with tall grasses (1-3m high) and trees (up to 15m high) characterize the vegetation of Benue State. The trees are mostly savanna trees with short boles, thick barks and broad leaves.

Population of the Study and Sample Size

The population of this study comprise sawn wood marketers in Benue State. Five LGAs were selected for this study. The LGAs selected are Gboko, Makurdi, Otukpo, Okpokwu and Katsina-ala. The total population of sawn wood marketers in the selected LGAs was 259. A sampling intensity of 38.6% was used to select the sample sizes from the total population in each of the LGAs and then added up to make a total of 100 respondents that were selected from all the selected LGAs. The total population and sample sizes of sawn wood marketers according to the LGAs are shown in Table 1.

Table 1: Population of sawn wood marketers and the distribution of respondents by LGAs

LGAs	Population of marketers	Sample size (38.6% of the population of marketers)
Gboko	39	15
Otukpo	51	20
Okpokwu	35	13
Katsina-ala	33	13
Makurdi	101	39
Total	**259**	**100**

Instrument of Data collection

One hundred (100) copies of semi-structured questionnaires and oral interviews were used to obtain data from the respondents.

Data Analysis

Descriptive statistics (making use of means, frequencies and percentages) was used to compute the most marketed sawn wood species and dimensions in each of the selected LGAs. Frequency values of each of these wood species, as they appear in each of the selected LGAs, were ranked to

determine the most marketed sawn wood species and dimensions in the State.

Results

The Most Marketed Sawn Wood Species between 2007 and 2021 in Benue State

The result indicated that there were different types of sawn wood species and dimensions sold in the various sawn wood markets between 2007 and 2021 in Benue State. Some of the most marketed sawn wood species in the selected LGAs included; *Daniellia oliveri* (Agba*), Gmelina aborea* (Malina)*, Khaya ivorensis* (Mahogany)*, Ceiba petandra* (Akpu)*, Annogeisus leocarpus* (Maaki)*, Tectona grandis* (Teak) and *Melicia excelsa* (Iroko). *Mangifera indica* (Mango), *Pterocarpus angolensis* (Akwanmiri), *Parkia biglobosa* (Nune/Ugba/Iklenyi), *Isoberlinia doka* (Ububa/Akovo/Ataakpa), *Birlina spp* (Small Leaf), *Sterculia tragacantha* (Owen/Odu), *Pterocarpus erinaceus* (Ngaji/ Awambe/Ache), (Ebelebe), *Anthocleista djalonensis* (Odlobu/Odrobu / Kokoso), *Vitex doniana* (Hulugh /Udu) and *Erythrophloem suavolens* (Enee). All these species are similar to the 25 timber species reported by Sambe (2016) as the most common in Benue State. Some of these species have become scarce and in some cases unavailable in some of the timber markets in the State. The result of the most marketed sawn wood species in each of the selected LGAs is presented in Tables 2 to 6.

Table 2: The Most Marketed Sawn Wood Species in Gboko LGA of Benue State

Tree/species Botanical Names	**Trade names/ Common Name**	**Tiv Name**	**Idoma Name**
Daniellia oliveri	African basalm/ Agba	Chiha	Alla
Gmelina aborea	Gmelina	Malina	Melina
Khaya ivorensis	Mahogany	Har	Opi
Ceiba petandra	White cotton tree/Akpu	Vambe	Akpu/Igwu
Parkia biglobosa	Parkia	Nune	Ugba/Iklinyi
Annogeisus leocarpus	Chewing stick tree/ Maaki	Maaki	Otla
Tectona grandis	Teak	Kpaah Kubuter	Utiki
Birlina spp	Small Leaf	Kpine	Atakpa

Pychnanthus angolensis	Akwanmiri	Kon awambe	Akwa
Mangifera indica	Mango	Mangor	Mangor

Source: Field Survey, 2021

Table 3: The Most Marketed Sawn Wood Species in Katsina-ala LGA of Benue State

Tree/species Botanical Names	**Trade names/ Common Name**	**Tiv Name**	**Idoma Name**
Daniellia oliveri	African basalm/ Agba	Chiha	Alla
Gmelina aborea	Gmelina	Malina	Melina
Khaya ivorensis	Mahogany	Har	Opi
Ceiba petandra	White cotton tree/Akpu	Vambe	Akpu/Igwu
Parkia biglobosa	Parkia	Nune	Ugba/Iklinyi
Annogeisus leocarpus	Chewing stick tree/ Maaki	Maaki	Otla
Melicia excelsa	Iroko	Leke	Uloko
Tectona grandis	Teak	Kpaah Kubuter	Utiki
Isobelina.doka	Isobelina	Akovol	Attakpa
Sterculia tragacantha	Sterculia	Owen	Okoko

Source: Field Survey, 2021

Table 4: The Most Marketed Sawn Wood Species in Makurdi LGA of Benue State

Tree/species Botanical Names	**Trade names/ Common Name**	**Tiv Name**	**Idoma Name**
Daniellia oliveri	African basalm/ Agba	Chiha	Alla
Ceiba petandra	White cotton tree/Akpu	Vambe	Akpu/ Igwu
Mitrigyna ciliata	Uburu	Lwagh	Obebe
Gmelina aborea	Gmelina	Malina	Malina
Melicia excelsa	Iroko	Leke	Uloko
Khaya ivorensis	Mahogany	Har	Opi
Annogeisus leocarpus	Chewing stick tree	Maaki	Otla
Pychnanthus erinaceus	Ngaji	Awambe	Ache
Parkia biglobosa	Parkia	Nune	Ugba/Iklinyi
Tectona grandis	Teak	Kpaah Ku Uke	Utiki

Source: Field Survey, 2021

Table 5: The Most Marketed Sawn Wood Species in Okpokwu LGA of Benue State

Tree/species Botanical Names	**Trade names/ Common Name**	**Tiv Name**	**Idoma Name**
Danielli oliveri	African basalm/ Agba	Chiha	Alla
Ceiba petandra	White cotton tree	Vambe	Akpu/ Igwu
Pychnanthus angolensis	Akwanmiri	Kon awambe	Akwa
Gmelina aborea	Gmelina	Malina	Melina
Afrormorsia elata	Ebelebe	-	-
Melicia excelsa	Iroko	Leke	Uloko
Khaya ivorensis	Mahogany	Har	Opi
Anthocleista djalonensis	Odrobu	-	-
Vitex doniana	Vitex	Hulugh	Udu
Prosopis africana	Prosopis	Gbaaye	Okpehe

Source: Field Survey, 2021

Table 6: The Most Marketed Sawn Wood Species in Otukpo LGA of Benue State

Tree/species Botanical Names	**Trade names/ Common Name**	**Tiv Name**	**Idoma Name**
Daniellia oliveri	African basalm/ Agba	Chiha	Alla
Ceiba petandra	White cotton tree/Akpu	Vambe	Akpu/Igwu
Parkia biglobosa	Parkia	Nune	Ugba/Iklinyi
Erythrophloem suavolens	-	Koe	Enee
Gmelina aborea	Gmelina	Malina	Melina
Khaya ivorensis	Mahogany	Har	Opi
Annogeisus leocarpus	Chewing stick tree/ Maaki	Maaki	Otla
Tectona grandis	Teak	Kpaah Ku Uke	Utiki
Anthocleista djalonensis	Odrobu	-	-
Vitex doniana	Vitex	Hulugh	Udu

Source: Field Survey, 2021

However, based on the frequency of appearances of the most marketed sawn wood species between 2007 and 2021 in each of the selected LGAs, the most marketed sawn wood species between 2007 and 2021 in the State included *Daniellia oliveri* (Agba*), Gmelina aborea* (Malina)*, Khaya ivorensis* (Mahogany)*, Ceiba petandra* (Akpu)*, Anthocleista djalonensis (Odrobu*)*, Parkia biglobosa* (Nune), *Annogeisus leocarpus* (Maaki)*, Tectona grandis* (Teak) and *Melicia excelsa* (Iroko). The result also indicated that *Daniellia oliveri* (Agba), *Ceiba petandra* (Akpu), *Gmelina aborea* (Malina) and *Khaya ivorensis* (Mahogany) appeared among the most marketed species in all the five selected LGAs in the State. Except for Okpokwu LGA, *Annogeisus leocarpus* (Maaki), *Tectona grandis* (Teak) and *Parkia biglobosa* (Nune) appeared among the most marketed sawn wood species in the other four LGAs. *Melicia excelsa* (Iroko) appeared among the most marketed sawn wood species in Okpokwu, Katsina-ala and Makurdi LGAs; while *Anthocleista djalonensis* (Odrobu) appeared among the most marketed sawn wood species in Okpokwu and Otukpo LGAs. The result of the most marketed sawn wood species in Benue State is presented in Table 7.

Table 7: The Most Marketed Sawn Wood Species in Benue State

Tree/species Botanical Names	**Trade names/ Common Name**	**Tiv Name**	**Idoma Name**
Daniellia oliveri	African basalm/ Agba	Chiha	Alla
Gmelina aborea	Gmelina	Malina	Melina
Khaya ivorensis	Mahogany	Har	Opi
Ceiba petandra	White cotton tree	Vambe	Akpu/Igwu
Anthocleista djalonensis	Odrobu	Kokoso	Odlobu/Odrobu
Annogeisus leocarpus	Chewing stick tree	Maaki	Otla
Tectona grandis	Teak	Kpaah Ku Uke	Utiki
Melicia excelsa	Iroko	Leke	Uloko
Parkia biglobosa	Parkia	Nune	Ugba/Iklinyi

Source: Field Survey, 2021

These species, according to the marketers, were most marketed in the State because of their relative availability, affordable prices, resistance to attack by insects, and strength needed for construction works. Most of these wood species are also similar to those reported by Popoola (1998) and Idoko (2007) as the most marketed sawn wood species in Benue State between 1985 and 1996 and between 1996 and 2007 respectively. The only exceptions are *Anthocleista djalonensis* (Odrobu) and *Parkia biglobosa* (Nune). Some wood species such as *Mansonia altisima* (Mansonia), *Nuclea diderichii* (Opepe) and *Triplochiton scleroxylon* (Obeche), which were reported by Popoola (1998) and Idoko (2007) as being among the most marketed sawn wood species in Benue State in the past, have become very scarce in the State. This is a result of shortages in supply, occasioned by the high costs of purchase and transportation from the States where they were bringing them from. When available, their prices compared to those of similar woods found in the State are higher than most would-be consumers cannot afford. Similarly, some dimensions of some species, such as *Tectona grandis* (Teak), *Melicia excelsa* (Iroko), *Mitrigyna ciliata* (Uburu), have also become difficult to find in most of the timber markets in the State. This has resulted in the use of species that were hitherto not used for timber in the State. Such species, such as *Mangifera indica* (Mango), *Prosopis africana* (Gbaaye/Okpehe), *Parkia biglobosa* (Nune/Ugba), *Vitex doniana* (Udu) etc, that were formerly valued for firewood and their fruits are now among the most marketed sawn wood species in the State. Most of the most marketed wood species in Benue State are available in large quantities within the State. Kalu and Ani (2009), Okunomo (2010), Arowosoge *et al.* (2011) and Tukur *et al.* (2013) reported that because of the reliable qualities of some of these species, particularly strength, quality, availability, resistance to attack by insects and affordable prices, they are very useful and significant in construction and furniture works. Ogunwusi (2012) noted that in nearly all ecological zones, the wood species mostly found in the timber markets are those widely available within the forests in such zones.

Most Marketed Sawn Wood Dimensions in Benue State

The result indicated that different dimensions of sawn wood were available in the various sawn wood markets between 2007 and 2021 in Benue State. Among these, the most marketed dimensions of sawn wood available in the State are 2 in. x 12 in. x 12 ft., 1 in. x 12 in. x 12 ft. (plank), 1 in. x 6 in. x 12 ft. (half plank), 2 in. x 2 in. x 12 ft., 2 in. x 3 in. x 12 ft., 2 in. x 4 in. x 12 ft. and 2 in. x 4 in. x 18 ft.(over-length). The result is presented in Table 8.

Table 8: Most marketed sawn wood dimensions in Benue State

British measures	**Metric measures**
Thickness x Width x Length	**Thickness x Width x Length**
1 inch x 12 inches x 12 ft	0.0254 m x 0.30408 m x 3.66 m

2 inches x 12 inches x 12ft	0.0508 m x 0.3048 m x 3.66 m
1 inch x 6 inches x 12 ft	O.O254 m x 0.1524 m x 3.66m
2 inches x 2 inches x 12 ft	0.05 08 m x 0.0508 m x 3.66m
2 inches x 3 inches x 12 ft	0.0508 m x 0.0762m x 3.66 m
2 inches x 4 inches x 12 ft	0.0508 m x 0.1016m x 3.66 m
2 inches x 4 inches x 18 ft	0.0508 m x 0.1016m x 5.49 m

Source: Field Survey, 2021.

All these dimensions corresponded with those reported as available in timber markets in Benue State by Sambe (2016), with the only exception of 1 in. x 9 in. x 12 ft. Other dimensions are sawn based on customers' requests. There is also the overlength of all these dimensions measuring 18 feet instead of 12 feet. They are also sawn based on the request of the customers. However, the most marketed of these common dimensions of sawn wood sold in the State is the 1 in. x 12 in. x 12 ft. (plank) with a 30.4% sales rate. It is closely followed by 2 in. x 4 in. x 12 ft. with a 28.7% sales rate. Next is the 2 in. x 3 in. x 12 ft. with 26.0 % sales rate; 2 in. x 2 in. x 12 ft. has 8.8 % sales rate; 1 in. x 6 in. x 12 ft. (half plank) 4.4 % sales; while the least marketed is the 2 in. x 12 in. x 12 ft. with 1.7% sales rate. The result is shown in Figure 3.

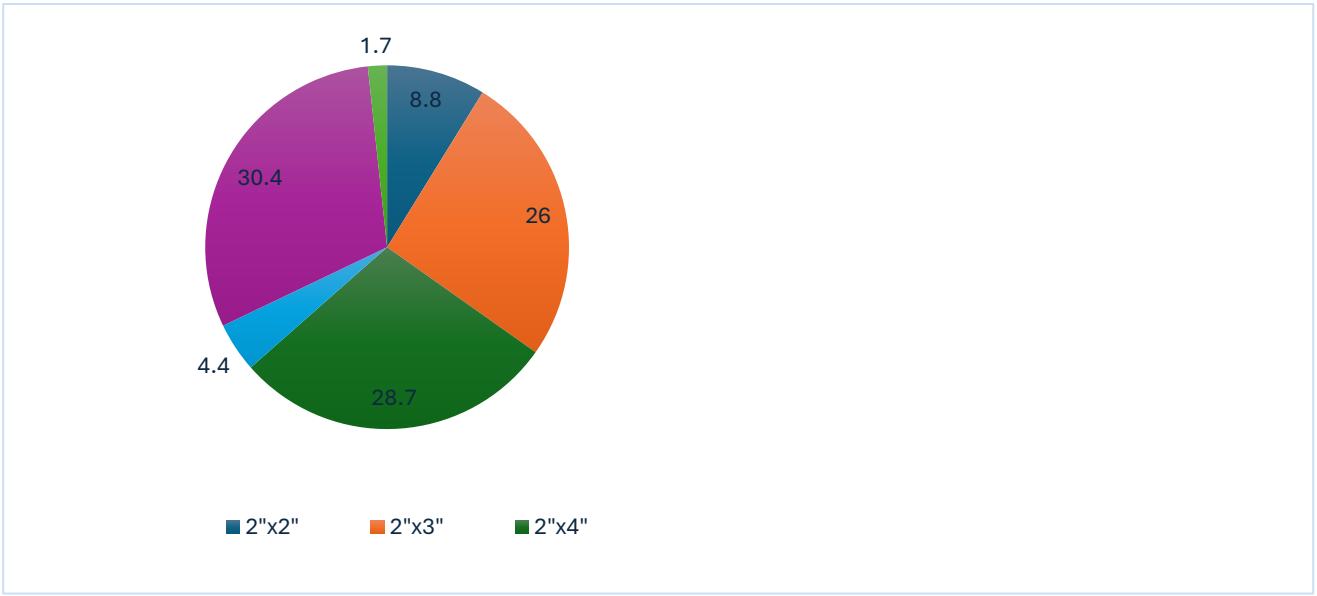

Figure 3: Dimensions of sawn wood sold mostly in Benue State

The reasons for the high rate of sale of 1 in. x 12 in. x 12 ft. (plank) in the State are;

(a) It is the major dimension of wood used for lintel construction
(b) It is the major dimension of wood used for the construction of coffins and furniture
(c) It is also the major dimension of wood used for the construction of deckings
(d) It is used for the construction of septic tanks ('suck-aways')
(e) It is a very important component of roofing and
(f) It is an important component of POP construction

As a result of these diverse uses of planks, timber marketers from other States of the country come to buy them in large quantities from timber markets in Benue State. Such States where they come from include Gombe, Nassarawa, Borno, Bauchi, Anambra, Enugu, the FCT etc. Planks of *Daniellia oliveri* (Agba) and *Ceiba petandra* (Akpu), which are very common in Benue State, are mostly bought.

CONCLUSION

Different sawn wood species and dimensions are sold in the various timber markets across Benue State. Availability, strength, price and quality are the major factors influencing the purchase and sales of sawn wood in the State. Over the years, some sawn wood species that were dominant in most of the timber markets in Benue State have become scarce and unavailable. This was a result of over-exploitation, and high costs of purchase and transportation. *Daniellia oliveri* (Agba) and *Ceiba petandra* (Akpu), *Gmelina aborea* (Malina) and *Khaya ivorensis* (Mahogany) are the most available and marketed timber species in the State. Similarly, different dimensions of sawn wood are also available across the various timber markets in the State. Purpose of utilization is the major factor affecting the purchase of these dimensions. Planks (1 in. x 12 in. x 12 ft.) were the most marketed dimensions as a result of their diverse uses. It was observed that most of the dimensions of sawn wood available in some timber markets in the State are not the actual measurements. For instance, a 2 in. x 4 in. x 12 ft. wood displayed in a market could be measuring 1 and half in. x 3 in. x 10/11 ft. This affects pricing as most unsuspecting customers are short-changed by this process. Competition in prices is also affected, as marketers that engage in such practices tend to sell such woods cheaper and attract more customers than the others. It is, therefore, recommended that the Benue State government set up a mechanism for certification and quality control of sawn wood products. Enforcing quality control measures and certification of standards in the sawn wood industry in the State is paramount for ensuring consumer safety, meeting regulatory standards and accessing premium markets. The government should also come up with policies that will encourage afforestation/reforestation and discourage deforestation. Such policies should include making land available for tree planting, providing incentives and inputs, such as seedlings, to those interested in embarking on tree planting, creating awareness of the importance of trees and the dangers/effects of deforestation and preventing illegal logging and encroachment in our forests

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AGROFORESTRY PRACTICES AND FOOD SECURITY IN SUB-SAHARAN AFRICA: THE NEXUS.

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ABSTRACT

Growing populations and the depletion of agricultural land are creating enormous challenges for the sustainability of food production. The declining quantity and quality of agricultural land, together with water scarcity and climate variability, threatens global food security. Agroforestry has over the years contributed undeniably to food security in sub -Saharan African. In this context, different agroforestry practices that aid food security were discussed. Several agroforestry foods such as vegetables, fruits, dairy, and meat are important to human nutrition; the production of such foods in conventional agriculture has contributed to negative environmental and social effects, e.g., climate change, biodiversity, ecosystem and land degradation, water scarcity, and stressed social structures

INTRODUCTION

Trees inside and outside forest contribute to food security in Africa. Agroforestry systems being practiced in sub-Saharan Africa provide space food, fuelwood, fibre, fodder and other products that are used at home or sold for income. Agroforestry, also, provide ecosystem services that important and critical for improved livelihoods. By combining trees and / or livestock, agroforestry diversifies both farm and non -farm activities. This creates diverse livelihood strategies that help households to deal with recurrent shocks, such as drought and lean periods and can make livelihoods more sustainable over time. Many smallholder farmers in sub-Saharan Africa practice agroforestry. These systems have prevailed despite persistent attempts to introduce monoculture production of annual crops which have been much less successful in Africa than elsewhere. Apart from providing edible products, agroforestry trees support food production by a range of other means, including by providing shade and support for crops that need it, supporting animal production and improving soil fertility (FAO,2011). Agroforestry has an important role in increasing the yields of vegetables that, with fruit, provide varied and nutritionally-balanced diets rather than calories alone (Susila *et al*. 2012). Trees can modify the microclimate for garden crops under harsh climates and support climbing plants such as yam (Maliki *et al*. 2012). Agroforestry trees provide important ecosystem services including: soil, spring, stream and

watershed protection; animal and plant biodiversity conservation; and carbon sequestration and storage, all of which ultimately affect food and nutritional security.

The forms of agroforestry system can be a combination of commodities, such as agri-silviculture, silvofishery, silvopasture, agrosilvofishery, agro-silvopasture, and apiculture. The main requirement of an agroforestry system is that there are tree stands as the main component.

On the other hand, food security is a condition that is best described as access by all of adequate and nutritious diet to maintain a healthy living. According to Food and Agricultural Organisation FAO (2002), food security can be defined as ensuring that all people at all times have both physical and economic access to enough food for an active and healthy life. Food security has been noted to constitute a fundamental challenge to people's welfare and economic growth in developing countries of sub-Saharan Africa.

Concept of food security

According to the World Food Summit organised in Rome in 1996, food security exists when all people, at all times, have physical and economic access to sufficient, safe, nutritious food to meet their dietary needs and food preferences for an active life.The Directorate, Food Security within the Department of Agriculture, Forestry andFisheries, Food and Agriculture Organisation of the United Nations (FAO), as well as theCentre for Poverty, Employment and Growth (CPEG) of the Human Sciences ResearchCouncil (HSRC) acknowledged that food security has three dimensions namely food availability, food access and food use. Food availability in the definition implies that a country must have sufficient quantities of food available on a consistent basis at both national and household level. Food access implies the ability of a nation and its households to acquire sufficient food on a sustainable basis. Food use refers to the appropriate use based on knowledge of basic nutrition and care, as well as adequate water and sanitation (FAO, 2003).

According to World Health Organization WHO (2015), food security means that all people at all times have both physical and economic access to enough food for an active and healthy life.

- The ways in which food is produced and distributed are respectful of the natural processes of the earth and thus sustainable.
- Both consumption and production of food are governed by social values that are just and equitable as well as moral and ethical.
- The ability to acquire food is ensured.

- The food itself is nutritionally adequate and personally and culturally acceptable.
- The food is obtained in a manner that upholds human dignity (Yadav, 2002). The levels of nutrient requirement as designed by the world health organization (WHO) and the food and agricultural organization (FAO). The basic minimum requirement per individual was recommended to be 65grammes of protein and 250kcal of energy. Any deviation from these may result into malnutrition. The ability of a household to meet 2260kcal of energy and 650g crude protein per capita is considered food secure below which it would be food insecure (Omotesho and Lawal, 2009).

Concept of Agroforestry

Agroforestry is a form of land use system that has been practiced for thousands of years by farmers all over the world. Its development as a science has been helping small holder farmers to increase their output, profitability and sustainability of production on their land. It involves the concurrent and deliberate cultivation of trees, agricultural crops and animals in close combination with one another.According to World Agroforestry Centre (ICRAF) agroforestry is a dynamic, ecologically based natural resources management system that through the integration of trees on farms and in the agricultural landscapes diversifies and sustains production for increase social, economic and environmental benefits for land users at all levels. In short, agroforestry is an integrated management of rural land areas.An estimated 1.2 billion people in developing countries rely on agroforestry practices to sustain their agricultural productivity and income (FAO 2011).Agroforestry is a practice that has been utilized for many years, particularly in developing countries, and is now widely promoted as a land-use approach that yields both wood products and crops. It involves an integrated system of rural land resource management based on combining shrubs and trees with crops and/or livestock, whose interactions generate economic, environmental and social benefits (Mukadasi and Nabalegwa, 2008). Its practices offer many advantages such as crop and livestock protection, soil and stream conservation and protection, diversification of agricultural revenues through the production of timber and non-timber forest products, promotion of biodiversity, landscape enhancement and carbon sequestration (Amonum, *et al*., 2009). Succintly, agroforestry principles and practices have long been recognized and applied in tropical countries because of the desire for more environmentally responsible agricultural practices. An example

of this integration system is the taungya farming system, thus, some economic benefits associated with taungya system include provision of fuelwood, non-timber forest products (NTFPs), generation of household income, plantation establishment etc. Therefore, it minimizes cost at one hand and increases profit on the other hand. It creates employment for the people who are opportune to farm in the plots. Generally, agroforestry is suitable for low input conditions and fragile environments, involves interplay of socio-cultural values and is structurally and functionally more complex than monoculture (Amonum, *et al*., 2009).

Some agroforestry systems / practices that aid food security in sub-Sahara Africa include:

1. **Taungya systems**:This system involves multiple land use practices embracing both the production of forestry and agricultural crops. It is an agroforestry method whereby farmers plant or retain trees on their farmland, both for food, income, soil improvement and environmental amelioration and for shade during the harsh weather period. Integration of trees into agricultural systems leads to more efficient use of sunlight, moisture and plant nutrients than is generally possible by monocropping of either agricultural or forestry crop (Fagbemi,2002) as cited by (Alao and Shuaibu, 2013). Taungya systems have directly provided enough food for about 900,000 in the country (Nao, 2008) as cited by (Wiro and Ansa,2019).Taungya provides non -timber forest products (NTFP's) to farmers which comprise of a wide range of products such as fruits, seeds, roots, chewing gum, resin, medicinal plants, honey, bush meat, including birds (Okafor, 1994).

2. **Parkland** also known as scattered trees: Parklands are characterized by well grown scattered trees on cultivated and recently fallowed land (CTA, 2003). These parklands develop when crop cultivation on a piece of land becomes more permanent. The trees are scattered far apart so that they do not compete with their neighbours. Parklands consist of indigenous trees like *Parkia biglobosa, Vitellaria paradoxa, Tamarindus indica, Azadirachta indica*, etc. Parkland trees have the following characteristics: They are deep rooting, preferably reaching ground water table. They have capacity to fix nitrogen Produce litter that decomposes well and add as much as possible to soil organic matter.

3. **Alley cropping** as described by (CTA, 2003) is a system in which strips of annual crops are grown between rows of trees or shrubs preferably leguminous species. The tree provides nitrogen from the atmospheric fixation, recycle nutrients from the depth of soil, suppress weedsand increases organic matter content of the soil (Amonum *et al.,* 2009). Lining up of the woody plants in hedges should ensure that there is little interference with cultivation of the field.

4. **Windbreaks**: In this system, double rows of trees are planted around the boundary of a food

crop farm on a windward side. Each windbreak is 150m long with 100 trees planted at escapement of 3m x 3m. The advantage of this system is that windbreak reduce wind erosion at the same time produce forest alongside food security.

5. **Agrosilvofishery:** This agroforestry system involves combination of agriculture (planting crops), forestry (trees) and fisheries on the same piece of land for improved food security, environmental protection and community livelihoods. It enhances sustainable and diversify livelihood and ecosystem services. The benefit of this system is that it provides farmers with multiple income streams and in turn promotes food security.

6. **Apiculture:** is the science of rearing bees. Honey serves as food and medicine for man becauseit has high nutritional value which can be used to supplement diet of the people. It is a system whereby beehives are placed at strategic places within the agroforestry considering factors like sunlight, shade, trees and shrubs that provide nectar and pollen sources.

7. Forest gardening / home gardening

Forest-gardening is a low maintenance plantbased food production and agroforestry system based on woodland ecosystems, incorporating fruits and nut trees, shrubs, herbs vines and perennial vegetables which have yields directly useful to humans. Making use of companion planting, these can be intermixed to grow in a succession of layers (Musotsi *et al*., 2008).

Forest gardening is a prehistoric method of securing food in tropical areas. In tropical region it is known as home garden. Forest garden have been shown to be a significant source of income and food security for local populations. Forest gardens are common in the tropics using intercropping to cultivate trees, crops and livestock on the same land. The gardens are typically cultivated with a mixture of annual and perennial plants that can be harvested on a daily or seasonal bases (Belcher, 2005). Biodiversity that has an immediate value is maintained in home gardens as women and children have access to preferred products (Sunderland, 2011). Home gardens with their intensive and multiple uses provide a safety net for households when food is scarce. These gardens are not only important sources of food, fodder, fuel, medicines, spices, herbs, flowers, construction materials and income in many countries, they are also important for the insitu conservation of a wide range of unique genetic resources for food and agriculture(Kebebew *et al.,* 2011). Home gardens are often a refuge for wild species threatened by deforestation and urbanization, and in periods of drought when the wild relatives suffer, those surviving in the home gardens provide considerable additional value to farm households (Musotsi *et al*., 2008).

Udofia (2007) opined that home garden is an assemble of deliberate chosen

species of plants and animals of human utility combined so as to mimic a natural climax system. It is known for its stable yields, varied products, continuous or repeated harvesting throughout the year (Wayja- musukwe and Mbalule, 2001). Also, fruits and vegetables cultivated in home gardens contribute significantly to food intake, nutritional requirements and income generation of both rural and urban population (Oladele and Labode, 2014). According to (Aweto, 2014) home gardens supplement food and fruits supplies from farms that are far from settlement. Stloukal *et al*., (2013) stated that trees on farms are a direct source of food, cash income and a range of subsistence benefits for billions of people.

Contribution of Agroforestry systems to Food Security in sub-Sahara Africa

Provision of Income

Agroforestry provides incomes to support access to food. Examples from Africa of widely traded agroforestry tree foods that support farmers' incomes include the indigenous semi-domesticated and widely cultivated fruit safou (*Dacryodes edulis*, Schreckenberg et al. 2006), the indigenous incipient domesticate shea nut (*Vitellaria paradoxa*,) Masters and Addaquay 2011) and the most popular African locust bean(*Parkia biglobossa*). The production of timber and other agroforestry tree products for markets also provide incomes for food purchase. Many trees are cultivated to provide medicines from bark, leaves, roots, 4 etc., which are sold to support incomes and are used for selftreatment, supporting the health of communities along with the provision of healthy foods (Muriuki et al. 2012).

Fuel and food production

Traditional energy sources have received little attention in current energy debates, but firewood and charcoal from trees are crucial for the survival and well-being of perhaps two billion people, enabling them to cook food to make it safe for consumption and palatable and to release the energy within it (FAO 2008). In sub-Saharan Africa, the use of charcoal is still increasing rapidly, with the value of the charcoal industry there approximately USD 8 billion in 2007 (World Bank 2011). The charcoal industry is therefore important for food and nutritional security, because it produces both energy and income; with the increasing prices of 'modern' energy sources, this situation is unlikely to change for some time.

Access to cooking fuel

Reduced access and increased prices of wood-based biomass have led to initiatives to promote agroforestry cultivation. Where smallholders practise agroforestry, less fuelwood needs to be purchased, there is less reliance on collecting from natural stands, and less time is involved in collection. This leaves more time for income-generating activities, especially for women who are usually the major fuelwood collectors (Thorlakson and Neufeldt, 2012). Access to cooking fuel provides people with more

flexibility in what they can eat, including foods with better nutritional profiles that require more energy to cook. The cultivation of woodlots allows the production of wood that is less harmful when burnt and has higher energy content. The use of better stoves – with greater efficiency – reduces greenhouse gas emissions relative to the energy generated for cooking purposes.

Conclusion

Agroforestry practices has contributed immensely to the food security of the people in the sub -Saharan Africa. The system plays a significant role in increasing the yield and income of households and also improve their livelihood by actively participating in agroforestry.Several agroforestry foods such asvegetables, fruits, dairy, and meat are important to human nutrition The advantages of agroforestry are quite enormous by striving to optimize the use of land for agricultural production on a sustainable basis and at the same time deriving other benefits from forestry.

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SOIL FERTILITY ENHANCEMENT BY TERMITE ACTIVITY: IMPLICATIONS FOR SUSTAINABLE FOREST MANAGEMENT

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ABSTRACT

In the arid Sahelian zones of West Africa, soil properties significantly influence sapling survival, particularly in degraded and nutrient-poor landscapes. Termite mound soils exhibit unique physicochemical characteristics such as enhanced nutrient content, improved structure, higher organic matter, and better moisture retention that create favourable conditions for tree establishment and growth. This review highlights the critical role termite mounds play in supporting reforestation, agroforestry, and soil rehabilitation initiatives. Their fertility and structure have been shown to reduce sapling mortality and accelerate early growth, especially in drought-prone or degraded areas. In agroforestry systems, integrating tree crops near termite mounds improves nutrient cycling, crop yields, and soil microclimates, reducing the dependence on chemical fertilizers. Furthermore, termite mounds contribute to essential ecosystem services including nutrient cycling, biodiversity enhancement, and increased soil resilience—key attributes for sustainable land management in the face of climate change. Applications in soil rehabilitation have demonstrated that termite mound soils can restore degraded lands by enhancing soil productivity and structure. Recognizing termites as ecosystem engineers opens up new opportunities for sustainable forest and agricultural management practices. The integration of termite mound soils into land use systems not only improves productivity but also aligns with ecological restoration goals. Future research should explore the scalability of termite mound applications across varying climatic zones and develop collaborative, locally adapted approaches for implementation. These findings underscore the value of termite mounds in promoting long-term ecosystem health, sustainability, and resilience in agroecological systems.

Keywords: Termite mound soils, Fertility, Physicochemical, Drought, Ecosystem, Sustainable, Management,

1.0 INTRODUCTION

Soil quality is one of the most important factors influencing plant health, productivity, and ecosystem functioning. In tropical and

subtropical ecosystems, termites play a critical role in modifying soil properties and structure, primarily through the construction of mounds that serve as their habitats. These structures—often conspicuous features of the landscape—are formed by the accumulation of soil particles, organic matter, and saliva, which termites meticulously transport and mix from various soil horizons (Jouquet *et al*., 2011). As ecosystem engineers, termites significantly influence the physical, chemical, and biological characteristics of soils, leading to marked differences between termite mound soils and adjacent soils (Lavelle *et al.,* 2006). Termite mound soils are frequently enriched with nutrients such as nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), and organic carbon (C), compared to surrounding soils (Fall *et al.,* 2001; Lopez-Hernandez, 2001). Additionally, their improved soil texture—often with higher clay content—enhances water-holding capacity and cation exchange capacity, which are favorable conditions for plant growth (Jouquet *et al.,* 2004). These enriched soil conditions can create localized "fertility islands," particularly beneficial in nutrient-poor and highly weathered tropical soils where conventional soil fertility is low (Ackerman *et al*., 2007). Consequently, termite mounds have become a focus of interest in ecological and agricultural studies for their potential role in enhancing plant productivity.

In agroforestry and reforestation systems, termite mound soils have been shown to support better tree growth, greater aboveground biomass, and higher crop yields (Ericksen *et al*., 2006; Traoré *et al.,* 2008). For example, studies in savanna and dry forest ecosystems have demonstrated that trees planted on or near termite mounds exhibit increased height, stem diameter, and leaf area, relative to those grown on surrounding soils (Dangerfield *et al*., 1998; Muvengwi *et al.,* 2013). This enhanced performance is often attributed not only to improved nutrient availability but also to changes in soil pH, porosity, and microbial activity, which collectively create a more favorable rhizosphere environment (Jouquet *et al.,* 2006). Despite the growing body of knowledge on termite-soil-plant interactions, comprehensive reviews examining the direct and indirect influence of termite mound soil physiochemical properties on tree growth and yield remain limited. A deeper understanding of these relationships is essential, particularly in the context of sustainable land use, climate change mitigation, and soil fertility management. This review, therefore, aims to synthesize current research on how termite-induced m

odifications in soil properties affect tree development and productivity. By evaluating studies from diverse ecological regions, the review seeks to highlight the ecological significance and practical potential of termite mounds in enhancing tree-based land use systems.

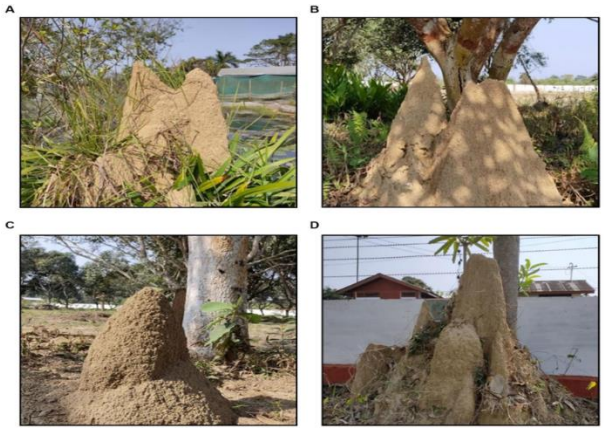

Figure 1: (**A–D)** Selected mounds of *Odontotermes obesus* for collection of termite mound soil.

2.0 PHYSICOCHEMICAL PROPERTIES OF TERMITE MOUND SOIL BASEDON NUTRIENT ENRICHMENT

Termite mound soils are recognized for their significantly enhanced physicochemical properties compared to adjacent surrounding soils. These unique properties are primarily due to the foraging, tunneling, and mound-building behavior of termites, which involves the selective collection, ingestion, and deposition of soil and organic matter. As a result, termite

+mounds serve as nutrient-rich microsites that can influence vegetation dynamics and productivity (Jouquet *et al.*, 2011; Muvengwi *et al.,* 2013). Termite mound soils are often enriched with essential macronutrients such as nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), and magnesium (Mg). This nutrient enrichment is linked to the decomposition of organic materials that termites bring into the mound for food and nest construction. For example, Lopez-Hernandez (2001) found that mounds of *Nasutitermes ephratae* in Venezuelan savannas contained significantly higher concentrations of total N and available P compared to surrounding soils. Similarly, Fall *et al*. (2001) reported elevated nitrate and ammonium levels in termite mounds, indicating intensified nitrogen cycling activity. Calcium is another critical nutrient found in higher quantities in mound soils, particularly in those built by *Macrotermes* species, which use saliva rich in calcium compounds to cement soil particles. This contributes to pH stabilization and increased base saturation, making these soils less acidic and more suitable for plant growth (Jouquet *et al.,* 2004). Due to their higher clay and organic matter content, termite mound soils possess a greater cation exchange capacity, a measure of the soil's ability to hold and exchange positively charged ions (e.g., K^+, Ca^{2+}, Mg^{2+}). This property is crucial for sustaining long-term nutrient availability and minimizing leaching, especially in regions with high rainfall or sandy soils (Lavelle & Spain, 2001).

2.1 Soil Organic Matter and Carbon Content

Soil organic matter (SOM) and soil organic carbon (SOC) are fundamental indicators of soil fertility, health, and biological activity. They play critical roles in improving soil structure, enhancing water retention, increasing cation exchange capacity (CEC), and supporting

microbial activity—all of which contribute to improved plant growth and productivity. Termite mound soils are often found to have significantly higher SOM and SOC levels compared to adjacent soils, largely due to the unique bioturbation and feeding behavior of termites (Jouquet *et al.,* 2011; Ackerman *et al.*, 2007). Termites collect and incorporate a wide variety of organic materials into their nests, including leaf litter, wood fragments, dead plant material, and fecal matter. This organic material, combined with fine soil particles, is cemented using termite saliva and deposited during mound construction. Over time, this results in an accumulation of organic residues and humified matter within the mound (Fall *et al.,* 2001). These activities create localized zones rich in organic carbon and nutrients, which act as hotspots of microbial and plant activity. According to Ackerman *et al.* (2007), termite mounds in the Amazonian forest soils contained two to three times more total organic carbon than surrounding soils, attributing the increase to long-term accumulation of organic inputs and reduced leaching due to denser soil aggregates. Lopez-Hernandez (2001) also reported elevated carbon levels in the termite mounds of the Venezuelan savannas, indicating that termites contribute significantly to carbon cycling in tropical ecosystems. The higher SOC in mound soils enhances nutrient retention and availability. Organic carbon improves soil aggregate stability, thus reducing erosion and increasing infiltration. It also serves as an energy source for soil microbes, leading to greater microbial biomass and activity (Lavelle *et al*., 2006). This, in turn, stimulates mineralization processes that release nutrients essential for plant uptake. Moreover, termite-induced carbon enrichment can have implications for climate change mitigation, particularly in degraded landscapes. Termite activity promotes carbon sequestration by incorporating surface litter into the soil matrix, effectively stabilizing organic matter against rapid decomposition (Jouquet *et al.,* 2006).

2.2 Soil Texture and Particle Size Distribution

Soil texture, the relative proportion of sand, silt, and clay is a critical property influencing soil fertility, water retention, aeration, and root penetration. In termite mound soils, the texture is often markedly different from that of the surrounding soils due to the selective behavior of termites in collecting and transporting soil particles for nest construction. This behavior results in distinctive particle size distribution patterns, typically skewed toward finer particles such as clay and silt, thereby modifying the physical environment of the soil (Jouquet *et al.,* 2002; Holt & Lepage, 2000).

2.2.1 Termite Preferences and Clay Enrichment

Termites particularly mound-building species such as *Macrotermes* and *Odontotermes* prefer

finer particles, especially clay, which they use to reinforce and stabilize the structure of their mounds. Clay particles are more cohesive, aiding in the construction of durable and weather-resistant mounds. As a result, termite mounds typically contain significantly higher clay content than surrounding topsoil (Mando *et al.,* 1996; Jouquet *et al*., 2004). For instance, Mando *et al.* (1996) found that termite mounds in semi-arid Burkina Faso exhibited 20–30% more clay than adjacent soils. Similarly, Jouquet *et al.* (2002) reported that termite mounds in tropical Asia and Africa showed a consistent trend of clay enrichment, leading to improved structural stability and water retention.

2.2.2 Impact on Soil Structure and Water Relations

The increase in clay and reduction in coarse particles like sand has multiple implications. Higher clay content enhances soil aggregate formation, which improves pore structure and water-holding capacity. This is particularly beneficial in arid and semi-arid environments where water is a limiting factor for plant growth. Termite mounds also often display improved soil porosity and infiltration rates, due to the bioturbation and tunnelling activities of termites (Fall *et al.*, 2001). In contrast, excessive clay may reduce aeration and increase compaction risks if not balanced with adequate organic matter. However, in termite mound soils, this is often offset by the concurrent increase in soil organic matter, which helps maintain favourable soil structure (Lavelle *et al.*, 2006).

2.2.3 Variability by Termite Species and Ecosystem

The degree of texture modification varies with termite species, soil type, and environmental conditions. *Macrotermes* mounds, for example, are more clay-rich than those built by other termite genera, owing to their sophisticated construction behaviour and use of salivary cementing agents (Jouquet *et al.*, 2011). Ecosystems such as savannas, dry forests, and grasslands tend to exhibit more pronounced textural differentiation in mounds due to the scarcity and value of fine particles in such settings.

3.0 SOIL PH AND ELECTRICAL CONDUCTIVITY

Soil pH and electrical conductivity (EC) are vital indicators of soil chemical status and fertility, influencing nutrient availability, microbial activity, and overall plant growth. Termite mound soils often show distinct variations in these parameters compared to adjacent soils, mainly due to termite-mediated transport of organic and inorganic materials and the biochemical alterations associated with mound construction and maintenance.

3.1 Soil pH: Moderation Toward Neutrality

One of the most consistent findings across ecosystems is that termite mound soils tend to have a higher and more neutral pH than surrounding soils (Jouquet *et al.*, 2011; Lopez-Hernandez, 2001). In many tropical and subtropical regions, native soils are naturally acidic due to intense weathering and leaching. However, termite activity tends to counteract this acidity by accumulating base-forming cations such as calcium (Ca^{2+}), magnesium (Mg^{2+}), and potassium (K^{+}), which help neutralize hydrogen ions in the soil solution (Fall *et al.*, 2001). For instance, Lopez-Hernandez (2001) found that termite mound soils in the Venezuelan savannas had significantly higher pH values (approaching neutrality) compared to the surrounding acidic savanna soils. This buffering effect enhances nutrient availability, particularly for phosphorus and micronutrients like molybdenum, which are less available in acidic conditions (Brady & Weil, 2010). Increased pH also improves microbial activity, especially for bacteria involved in nitrogen cycling and organic matter decomposition, further contributing to enhanced soil fertility (Jouquet *et al*., 2004).

3.2 Electrical Conductivity (EC): Indicator of Ion Accumulation

Electrical conductivity measures the total soluble salt concentration in soil and is a proxy for the availability of ionic nutrients. Termite mound soils typically exhibit moderately higher EC values than surrounding soils due to the accumulation of soluble bases and nutrients introduced via termite foraging, plant debris, feces, and other organic inputs (Fall *et al*., 2001; Muvengwi *et al.,* 2013). While high EC values can be a concern in saline or sodic soils, the levels observed in most termite mounds are beneficial rather than detrimental, indicating enhanced nutrient availability without toxicity. This enrichment supports vigorous root activity and early-stage plant development, making termite mounds valuable microsites for natural regeneration or agricultural exploitation (Jouquet *et al*., 2006). In a study in West Africa, Mando *et al.* (1996) noted that termite mounds had higher EC readings than surrounding crusted soils, coinciding with higher concentrations of exchangeable Ca and Mg important macronutrients for plant structural and physiological functions.

4.0 EFFECTS ON TREE GROWTH AND YIELD

4.1 Enhanced Nutrient Availability and Growth Rates

Termite mound soils significantly contribute to enhanced tree growth rates due to their superior physicochemical properties compared to surrounding soils. These properties such as increased nutrient availability, higher organic matter content, neutral pH, improved water retention, and better soil structure create favourable conditions for root development, nutrient uptake, and physiological performance

of trees (Jouquet *et al.*, 2011; Muvengwi *et al.*, 2013). Termite mounds accumulate essential macro- and micronutrients like nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), and magnesium (Mg), which are vital for plant growth. These nutrients are often in more bioavailable forms due to the intense microbial activity and decomposition processes facilitated by termites (Lopez-Hernandez, 2001). As a result, trees growing on or near termite mounds often show higher biomass accumulation, increased height, and faster trunk diameter growth than those in termite-free soils (Mando *et al.*, 1996; Ayuke *et al.*, 2009).

4.2 Improved Root Penetration, Soil Aeration Water Retention

The bioturbation activities of termites enhance soil porosity and aggregation, which support deeper and more extensive root systems. This improves tree anchorage and allows for better access to nutrients and water stored deeper in the soil profile (Lavelle *et al*., 2006). The improved aeration also stimulates root respiration and microbial symbioses, such as those with mycorrhizal fungi, further boosting nutrient uptake and growth efficiency. Higher clay and organic matter content in termite mound soils increase water-holding capacity, which is particularly beneficial in arid and semi-arid ecosystems. This enhances tree survival and growth during dry seasons, as roots can access moisture longer than in sandy, non-aggregated soils (Jouquet *et al.,* 2002). Trees in such environments demonstrate greater tolerance to water stress, ensuring steady growth rates even under challenging climatic conditions.

4.3 Field Evidence of Enhanced Tree Growth

Field studies from tropical and savanna ecosystems consistently report improved tree growth metrics on termite mounds. For instance, Muvengwi *et al*. (2013) observed that native and planted tree species, including *Brachystegia spiciformis* and *Eucalyptus spp.*, exhibited significantly higher growth rates on termite mound soils in Zimbabwean miombo woodlands. Similarly, Erpenbach *et al.* (2013) reported that tree seedlings established on termite mounds in South African savannas had higher survival rates and faster vertical growth than those planted off-mound.

5.0 INCREASED BIOMASS PRODUCTION

The improvement in soil fertility and structure associated with termite mound soils directly contributes to increased biomass production in trees. Biomass, which includes both aboveground (leaves, stems, branches) and belowground (roots) components, is a critical indicator of tree vigor, ecosystem productivity, and carbon sequestration capacity. The enhanced nutrient status, water retention, and favourable pH of termite-modified soils create optimal conditions for sustained tree growth and

biomass accumulation (Jouquet *et al.,* 2006; Muvengwi *et al*., 2013).

5.1 Nutrient Enrichment Promotes Vegetative Growth

Termite mound soils are often rich in essential plant nutrients, such as nitrogen (N), phosphorus (P), and potassium (K), all of which are crucial for cell division, protein synthesis, and photosynthesis. The abundance and availability of these nutrients enable trees to invest more in leaf and wood production, which significantly boosts overall aboveground biomass (Lopez-Hernandez, 2001). Phosphorus, in particular, which is often limited in tropical soils, is typically more available in termite mound soils, supporting greater root and shoot development (Jouquet *et al.,* 2002). Improved soil structure and reduced compaction in termite mound soils allow roots to penetrate deeper and spread more widely, which increases belowground biomass. This enhances the plant's ability to access water and nutrients from a larger soil volume, promoting greater productivity even under moisture stress (Lavelle *et al.,* 2006). Additionally, the biologically active environment of termite mound soils encourages root-microbe interactions, such as mycorrhizal symbioses, further improving nutrient uptake efficiency.

5.2 Empirical Evidence of Biomass Gains

Numerous studies have documented increased biomass production in trees growing on termite mound soils. For example, Muvengwi *et al*. (2013) found that both native and exotic tree species planted on termite mounds in savanna ecosystems exhibited significantly higher aboveground and total biomass compared to those planted on non-mound soils. Similarly, Dangerfield *et al.* (1998) observed that trees in Botswana's Kalahari region had denser canopies and thicker stems when growing on or near termite mounds, reflecting enhanced productivity. In agroforestry and reforestation settings, utilizing termite mound soils or planting near termite mounds has been proposed as a strategy to boost early tree establishment and accelerate biomass accumulation, especially in nutrient-poor or degraded landscapes (Erpenbach *et al.*, 2013).

6.0 DROUGHT RESISTANCE

Drought resistance is a key adaptive advantage provided by termite mound soils, especially in tropical and semi-arid ecosystems where water availability often limits tree productivity. Termite mound soils confer improved resilience to drought stress through enhanced soil structure, increased organic matter content, and superior water retention capacity—all of which create more favorable conditions for trees to survive and grow during periods of water scarcity (Jouquet *et al.,* 2011; Mando *et al.,* 1996). Termite mound soils typically have higher clay and organic matter content

compared to adjacent soils (Jouquet *et al.,* 2002). These components are critical for retaining soil moisture, especially in regions characterized by irregular rainfall. The increased micropore space provided by clay particles helps retain water, making it available to plants over longer periods between rainfall events. This buffering capacity is crucial during dry spells, allowing tree roots to continue accessing water and maintaining metabolic activity.

6.1 Enhanced Root Growth and Soil Penetration

The bioturbation activities of termites improve soil structure and porosity, facilitating deeper root penetration. This allows trees to access water stored in deeper soil horizons, which becomes essential when surface moisture is depleted (Lavelle *et al.,* 2006). Deeper rooting systems also enable trees to extract moisture from a wider radius, increasing their resilience during prolonged dry periods. Termite mounds may also influence microclimatic conditions in their immediate vicinity, such as moderating temperature and reducing evapotranspiration due to higher soil moisture and organic matter. This helps reduce physiological stress on trees and supports their survival and productivity even under harsh environmental conditions (Dangerfield *et al.,* 1998).

6.2 Field Evidence Supporting Drought Tolerance

Empirical studies demonstrate that tree species growing on or near termite mounds show higher survival rates and sustained growth during drought periods. For example, Muvengwi *et al.* (2013) reported that tree seedlings established on termite mound soils in the Zimbabwean miombo woodlands experienced less drought-induced mortality than those planted on surrounding soils. Similarly, Traoré *et al.* (2008) found that termite-induced improvements in soil properties supported greater sapling survival in arid Sahelian zones of West Africa.

7.0 APPLICATIONS IN FORESTRY AND AGROFORESTRY

The unique characteristics of termite mound soils—ranging from enhanced nutrient availability to improved soil structure—offer significant potential for applications in forestry and agroforestry systems. By capitalizing on the ecological benefits provided by termite activity, both natural forests and agroforestry practices can be optimized to enhance tree growth, improve soil fertility, and increase productivity in a sustainable manner (Jouquet *et al.,* 2006; Muvengwi *et al.,* 2013).

7.1 Reforestation and Afforestation Efforts

In regions where soil fertility is poor or land degradation is a concern, termite mound soils offer an excellent opportunity to enhance reforestation and afforestation efforts. The

fertile, well-structured soils found in termite mounds can support the establishment and growth of tree species that would otherwise struggle in less favourable soil conditions (Muvengwi *et al.,* 2013). For instance, planting tree seedlings in or near termite mounds has been shown to accelerate establishment, promote early growth, and reduce mortality rates, especially in degraded lands or drought-prone areas (Erpenbach *et al.,* 2013). In tropical and subtropical regions, where reforestation is essential for carbon sequestration and biodiversity conservation, termite mound soils can act as natural fertility hotspots, providing an alternative to synthetic fertilizers and reducing the cost of reforestation programs (Lopez-Hernandez, 2001). In agroforestry systems, where trees are integrated with crops or livestock, termite mounds can play a vital role in improving soil fertility and tree-crop interactions. By planting trees on or near termite mounds, farmers can enhance nutrient cycling, increase crop yields, and reduce the need for chemical fertilizers (Muvengwi *et al.,* 2013). Termite mound soils often contain higher levels of organic matter, which helps improve soil structure, water retention, and microbial activity—all crucial for optimizing crop growth in integrated systems. In addition to supporting tree growth, termite mounds provide microclimates that reduce soil temperature and evaporation, making them particularly valuable in arid and semi-arid regions where water scarcity limits agricultural productivity (Jouquet *et al*., 2002). The presence of termites and their mounds also contributes to ecosystem services in agroforestry systems, including the cycling of nutrients, the enhancement of soil structure, and the improvement of biodiversity (Lavelle *et al.,* 2006). These ecosystem services not only support tree growth but also enhance the overall health and resilience of agroforestry systems, making them more sustainable in the face of climate change.

7.2 Soil Rehabilitation and Fertility Enhancement

Termite mounds can also be used as a tool for soil rehabilitation and improving land productivity in degraded ecosystems. In areas where conventional methods of soil fertility restoration are costly or ineffective, utilizing termite mound soils or integrating them into agroecological practices can significantly enhance the nutrient profile and water-holding capacity of degraded soils. This practice has been successfully implemented in regions of Africa, where termite mounds have been shown to act as natural fertilizer sources that can improve both soil structure and crop yields over time (Mando *et al.,* 1996).

8.0 CONCLUSION AND RECOMMENDATION

The unique physicochemical properties of termite mound soils—enhanced nutrient content, improved soil structure, better moisture

retention, and increased organic matter—offer significant benefits for tree growth and yield. These properties are the result of the complex interactions between termites and their environment, which leads to the formation of highly fertile, well-structured soils that support the establishment and growth of trees in a variety of ecosystems, particularly in areas where soil fertility and water availability are limited. The positive effects of termite mound soils on tree growth include increased root development, enhanced drought resistance, improved biomass production, and greater tree stability. These benefits are particularly critical in tropical, semi-arid, and degraded landscapes where natural soil conditions often impede agricultural and forestry productivity. By improving soil aeration, facilitating root penetration, and enhancing water and nutrient availability, termite mounds create an ideal environment for tree growth, especially in challenging environmental conditions. In agroforestry and reforestation efforts, termite mound soils offer practical applications by promoting tree establishment, increasing productivity, and reducing the need for chemical fertilizers. Termite mounds provide a sustainable, natural alternative to soil fertility restoration, particularly in degraded landscapes, and enhance biodiversity and ecosystem resilience. These findings underscore the potential for integrating termite mound soils into agroecological practices, forest management, and soil rehabilitation programs. By recognizing the role of termites as ecosystem engineers, forest and agricultural managers can harness their contributions to improve soil fertility, enhance tree growth, and support long-term sustainability.

Future research should focus on quantifying the full range of benefits offered by termite mound soils, exploring their potential in different climatic regions, and developing practical methods to integrate termite mound-based approaches into large-scale land management and restoration efforts. The findings of this review also highlight the need for collaborative approaches that involve local knowledge, indigenous practices, and modern science to maximize the positive impacts of termite mounds on tree growth and overall ecosystem health.

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Sub-Theme No 4: Adaptive Silvicultural Practices for Climate Resilience and Forest Sustainability.

Assessment of Biodiversity Composition of Yemoji Wetlands, Ogun State, Nigeria

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Abstract

Wetlands render ecosystem services and also provide livelihood to the people in and around the environment as well as militating against climate change. This paper assessed the biodiversity composition of yemoji wetlands with the aim to providing datum empirical information on the wetlands. Ecological surveys of mammals, birds, fishes and reptiles were carried out at a précised interval from October 2023 until October 2024. Forest survey was carried using two line transects established at both sides of yemoji river bank. Twenty temporary sample plots of 20m x 20m were laid in alternate position at an interval of 30m and central quadrant (5m x 5m) where trees and herbs were identified to species level. A total of 219 trees consisting of 28 taxa which belong to 18 families were encountered. Moraceae, Arecaceae, Rubiaceae, Fabaceae and Sterculiaceae were the dominant familes. About 1,564 herbs of 34 taxa in 22 families of herbs were encountered in the study area. Forty nine (49) mammals with 22 taxa in 19 families were encountered. Bovidae, Elapidae and Sciuridae were the primal families in the area. A total of 40 birds which composed 18 taxa in 16 families were counted. Accipitridae family species were the commonest in yemoji wetlands. About 28 fishes in 6 taxa belonging to 6 families were enumerated. Tillapia (Cichlidae), cat fish (clariidae) and Electric fish (Gymnotidae) were the dominant species. Further studies were recommended for soil biodiversity to increase the knowledge on yemoji wetlands.

KEYWORDS: Wetlands, Livelihoods, Trees, Herbs, Mammals, Birds, Fishes

1.0INTRODUCTION

Wetlands are waterlogged soil environments which are noticeable by the presence of water on the soil surface which could be non-seasonal or flooded at a certain period of the year (McCartney *et al.,* 2015). They are specialised ecosystems with characterised buffer capacity to absorb, retain and filter pollutants out of water that passes through the ecosystem over a long period of time. This systemic function made scientists to refer to them as "earth's kidneys" due to their purification and filtration capacity which is the reasons they are referred to as wetlands (Odubo *et al*., 2023). These ecosystems consist of hydric undrained soil substrate which favours the growth of hydrophytes during the growing season. Some common types of wetlands include wetprairie, sedge meadows, fens, seeps, marshes, mangrove swamps and bogs (Feierabend, 2020). Wetlands

are common along the coastlines and coastal communities around the world. Coastal settlements consist of rural and urban areas adjoining the coastal water bodies with terrestrial boundaries, unleashing these unique ecosystems for human activity (Hammer & Bastian, 2020). However, settlement expansion affects the ecological integrity of wetlands since it aggravates coastal degradation and siltation which reduces the environmental benefits of the ecosystem for humankinds. In most cases, unabated encroachment and degradation of wetlands often led to total depletion of the ecosystem. Nevertheless, this phenomenon can be prevented through coastal planning which enhances wetlands ecosystem services and urban protection (Wang *et al.*, 2022). Unfortunately, the development around coastal areas have impacted wetlands adversely through fauna loss of habitat from the constructions buildings, aggregation of fittings and pollutants such as plastics, iron as well as silt and organic matters which reduced water quality and resulted in hydrological changes (Yu *et al.*, 2023). The expansion of human entrepreneurial activities especially in the coastal and riverine areas has negatively impacted the aquatic organisms. Prominent among these organisms include water birds, fish species, molluscas, water quality and other alien species which depend on the ecosystem for survival. Sadly, the effects increased as a result of little or no efforts for restoration and conservation at different levels (Okonkwo *et al.,* 2015). This is occasioned by negligence on the part of individuals and government due to inadequate knowledge about the importance, species diversity and ecosystem services of wetlands environments in Nigeria.

Yemoji wetland also known as Yemoji River wetlands or "African River Jordan," is a significant natural water body in Ijebu area. The water is believed to have healing properties as well as sustain the livelihood of people around the area. Yemoji wetlands are essential for maintaining the balance of the local ecosystem and providing food and habitats for various species in the area. According to information from the people living around yemoji wetland, the water has some therapeutic and healing effects on the people and strangers that swim in the river. This led to the construction of the natural swimming pool which attracts many tourists from far and near to the area. Painfully, it was observed during the field survey that the wetland is experiencing significant changes due to human activities. The influx of tourists to Yemoji natural swimming pool and other farming and hunting activities are negatively impacting the ecosystem. This necessitated the inventory of biodiversity of this rich ecosystem to mitigate degradation and promote conservation of this scarce natural resource.

Stein *et al.* (2020) reported that human activities have been the main cause of wetland degradation over time resulting to many environmental hazards like erosion, land pollution, droughts, sea level rise, and storms.

Total loss of wetland often resulted in loss of ecological services and significant alterations in micro-climate and biodiversity loss. Unfortunately, the uncontrolled anthropogenic activities like hunting, farming, fishing, mass deforestation and expansion of settlement in the study area call for concern. Because the ecosystem have been a buffer zone that sustains the lives of both human and livestock in the area. Likewise, the potential tourist attraction and the therapeutic healing effects of yemoji wetlands water also attract the attention of this study to enhance the ecological services and possible conservation measures to prevent further degradation. Thus, this paper assessed the biodiversity of yemoji wetlands with the aim to providing datum empirical data of the flora and fauna species also to create awareness and the need to formulate conservation strategies to preserve these multipurpose wetlands.

2.0 MATERIALS AND METHODS

2.1StudyArea

This study was carried out in Yemoji wetlands in Ijebu Ode, Ijebu Ode local government area of Ogun State (Fig. 1). The study area is located between latitude 6º45'30"N – 6º45'30"N and longitude 3º57'50"E – 3º58'10"E. It is found after Imagbon along Epe – Ijebu Ode road in beautiful and serene environment. Ijebu Ode local government has a population of about 233,310 people. Ijebu people who are sub-group of the Yoruba ethnic group are the predominant tribe that live in the area. The soil type is mainly ferralitic, and the region experiences a tropical rainforest climate with an average annual rainfall of 1800mm.

Fig. 1: Map of Yemoji Wetlands in Ogun State (Inset red colour indicates the boundary)

2.2 METHODS

Ecological surveys of mammals, birds, fishes and reptiles were carried out at a précised time interval from October 2023 until October 2024. Fauna populations were assessed and documented every two weeks across the seasons either on foot or vehicle according to the suitability of the area. Observations were made using open ended line transect method and foot paths with the aid of 10x50 Olympus binoculars. Collection of data was supported with photography using Canon EOS 1000 D SLR camera. Net was used for fish's survey, while reptiles were assessed by visual encounter or sighting. The birds were watched along the line transect cum Point Count observation and identification by visual encounter as well as vocal/calls identification. Also, the pictorial guide to birds by Ali and Ripley (1995) was equally adopted for the identification of rare bird species.

Similarly, forest survey was carried using two line transects established at both sides of yemoji river bank. Twenty temporary sample plots of 20m x 20m were laid in alternate position at an interval of 30m apart where trees were identified to species level. Central quadrant of 5m x 5m was established in each plot to assess and identified the herb species. All the plots were contiguous and coordinates of each plot were collected with GPS and recorded on each slip of the forest inventory All data were recorded at the point of assessment to avoid bias and missing data.

2.3 Data Analysis

The data collected were analyzed using simple statistical tools such as frequency table, bar chart and percentages. Prospective formula was also used to compute the values for relative density (RD). Floristic analysis was used to determine the percentage of each botanical family. The number of species and floristic diversity were also determined using statistica 7 software.

Relative Density (RD): This determines the number of individual per hectare in the forest types using Eqn. 1

$$RD = \frac{ni}{N} \; x \; 100\%$$

Where n_i = number of individuals of each tree species i and N = total number of individuals in the entire tree population

3. 0 RESULTS AND DISCUSSION

3.1 Flora Composition of Yemoji Wetlands

The flora analysis of Yemoji wetlands forest ecosystem revealed that, a total of 219 stems of trees which consist of 18 taxa belong to 18 families were enumerated in the fringing forests of yemoji wetlands. *Elaeis guineensis* had the highest population in the wetland (RD, 22.37%), followed by ficus exaspirata with RD (12.79%), while Dalium guineense and Terminalia catapa had the lowest representation in the ecosystem with RD (0.91%) respectively (Table 1). These findings agreed with the report of Edo and Albrecht (2021) who documented that Elaeis guineensis and Ficus exaspirata are common species in wetland areas. The floristic analysis showed that the families of Moraceae (27.8%) and Arecaceae, Rubiaceae and Fabaceae with (11.1%) representation are the most dominant families in the wetlands ecosystem (Table 2). This is in line with the report of Kanaujia et al.(2018) who also discovered that these families are dominant in Lucknow, Uttah Pradesh, India. The dominant nature of moraceae and other families indicates their resilience to anthropogenic and environmental stress.

About 1,564 stands which comprised of 34 taxa belonging to 22 families of Herbs were encountered during the study (Table 3). Asteraceae, Areceae, Fabaceae and Euphorbiaceae families dominated the landscape (Table 4). This corroborated the findings of Aust et al. (2020) that herb species in these aforementioned families are dominant in tropical forests.

Table 1: Tree Species Composition of Yemoji Wetlands

S/N	Name of Species	Family	F	RD(%)
1.	*Ficus exaspirata*	Moraceae	28	12.79
2.	*Elaeis guineensis*	Arecaceae	49	22.37
3.	*Artocarpus altilis*	Moraceae	14	6.39
4.	*Trema orientalis*	Cannabaceae	18	8.22
5.	*Ficus mucuso*	Moraceae	11	5.02
6.	*Spondia mombin*	Anacardiaceae	8	3.65
7.	*Morinda lucida*	Rubiaceae	18	8.22
8.	*Mitragyna ciliate*	Rubiaceae	6	2.74
9.	*Cocos nucifera*	Arecaceae	9	4.11
10.	*Terminalia catappa*	Combretaceae	2	0.91
11.	*Newboldia laevis*	Bignoniaceae	21	9.59
12.	*Milicia excels*	Moraceae	4	1.83
13.	*Albizia zygia*	Fabaceae	14	6.39
14.	*Sterculia tragacantha*	Sterculiaceae	3	1.37
15.	*Ficus thompsonii*	Moraceae	5	2.28
16.	*Rauvolfia vomitoria*	Apocynaceae	3	1.37
17.	*Dalium guineense*	Fabaceae	2	0.91
18.	*Cola gigantean*	Sterculiaceae	4	1.83

Table 2: Family composition of Tree Species in Yemoji Wetlands

S/N	Family	Number of Species	Representation (%)
1	Moraceae	5	27.8
2	Arecaceae	2	11.1
3	Cannabaceae	1	5.6
4	Anacardiaceae	1	5.6
5	Rubiaceae	2	11.1
6	Combretaceae	1	5.6
7	Bignoniaceae	1	5.6
8	Fabaceae	2	11.1
9	Sterculiaceae	2	11.1
10	Apocynaceae	1	5.6

Table 3: Herb Species Composition of Yemoji Wetlands

S/N	Name of Species	Family	F	RD(%)
1.	*Urena lobata*	Malvaceae	6	0.38
2.	*Desmodium gangeticum*	Fabaceae	12	0.77
3.	*Centrosema pubescens*	Fabaceae	86	5.50
4.	*Panicum maximum*	Poaceae	23	1.47
5.	*Crassocephalum repens*	Asteraceae	4	0.26
6.	*Telfairia occidentalis*	Cucurbitaceae	11	0.70
7.	*Phyllanthus niruri*	Phyllanthaceae	18	1.15
8.	*Ocimum gratissimum*	Lamiaceae	4	0.26
9.	*Alchornea cordifolia*	Euphorbiaceae	22	1.41
10.	*Celosia argentea*	Amaranthaceae	14	0.90
11.	*Solanum nigrum*	Solanaceae	6	0.38
12.	*Capsicum frutescens*	Solanaceae	13	0.83
13.	*Colocasia esculenta*	Araceae	30	1.92
14.	*Manihot esculenta*	Euphorbiaceae	34	2.17

15.	*Musa sapientum*	Musaceae	123	7.86
16.	*Portulaca quadrifida*	Portulacaceae	60	3.84
17.	*Phyllanthus amarus*	Phyllanthaceae	165	10.55
18.	*Aspilia africana*	Asteraceae	58	3.71
19.	*Aframomum sceptrum*	Zingiberaceae	94	6.01
20	*Chromolaena odorata*	Asteraceae	82	5.24
21.	*Talinum triangulare*	Talinaceae	120	7.67
22.	*Sida acuta*	Malvaceae	46	2.94
23.	*Icaccina tracantha*	Icacinaceae	13	0.83
24.	*Calopogonium mucunoides*	Fabaceae	10	0.64
25.	*Asparagus africanus*	Asparagaceae	142	9.08
26.	*Euphorbia hirta*	Euphorbiaceae	33	2.11
27.	*Cyperus rotundus*	Cyperaceae	205	13.11
28.	*Combretum indicum*	Combretaceae	66	4.22
29.	*Borreria ocymoides*	Rubiaceae	14	0.90
30.	*Commelina legocensus*	Commenlinaceae	9	0.58
31.	*Tridax procumbens*	Asteraceae	15	0.96
32.	*Nymphaeae lotus*	Nymphaeaceae	12	0.77
33.	*Pistia stratiotes*	Araceae	8	0.51
34.	*Alocasia macrorrhizos*	Araceae	6	0.38

Table 4: Family Composition of Herbs in Yemoji Wetlands

S/N	Family	Number of Species	Representation (%)
1	Malvaceae	2	5.9
2	Fabaceae	3	8.6
3	Poaceae	1	2.9
4	Asteraceae	4	11.8
5	Cucurbitaceae	1	2.9
6	Phyllanthaceae	2	5.9
7	Lamiaceae	1	2.9
8	Euphorbiaceae	3	8.6
9	Amaranthaceae	1	2.9
10	Solanaceae	2	5.9
11	Araceae	3	8.6
12	Musaceae	1	2.9
13	Portulacaceae	1	2.9
14	Zingiberaceae	1	2.9
15	Talinaceae	1	2.9
16	Icacinaceae	1	2.9
17	Aparagaceae	1	2.9
18	Cyperaceae	1	2.9
19	Combretaceae	1	2.9
20	Rubiaceae	1	2.9
21	Commenlinaceae	1	2.9
22	Nymphaeceae	1	2.9

3.2 Fauna composition of Yemoji Wetlands

The fauna analysis of yemoji wetlands were categorised into three which include the

Animals (mammal), Birds (Aves) and Fish (pisces). There were 49 animals consisting of 22 taxa which belong to 19 families sighted in yemoji wetlands during the study (Table 5). Thryonomys swinderianus with RD (12.24%) and Cercopithecus mona with RD ((8.16%) were the dominant species in the wetlands ecosystem. This conformed to the report of Kanaujia et al. (2018), who documented that Mona monkeys and Glasscutters are the commonest species in wetlands. This species usually inhabits wetlands to secure sustainable food, protection from prey, fire and poachers as well as enabling environment for breeding. The family composition analysis revealed that Bovidae, Elapidae and Sciuridae were the primal families in the wetlands (Table 6). This corroborated the findings of Chatterjee and Bhattacharyya (2021), who opined that Sciuridae, Bovidae and Elapidae are usually the dominant families in wetland environments. Thus, conservation of wetlands should be a priority in the environmental plans of the government in order to sustain the ecosystem services (Barakagira and De wit, 2017).

About 40 birds with 18 taxa which belong to 16 families were encountered during the study (Table 7). Francolino bicalcaratus with RD (12.50%) and Milvus migrans, RD (10.0%) were the commonest terrestrial bird species in the wetlands. While Anas platyrhynchos and Centropus sinensis were the dominant aquatic birds in the area with RD (7.50%|) respectively. This is contrary to the report of Kamar et al. (2005), who reported Corvus albus and Buteo jamaicensis as the dominant bird species in tropical zones. Accipitridae family with 16.7% representation was the dominant family among the bird species sighted in the study area (Table 8). This is contrary to the report of Li and Mundkur (2004) that Anatidae and strigidae are the predominant families in tropical wetlands around the world. The dominance of Accipitridae family may be due to the resilience of the species and their ability to survive threats and adverse conditions. Ramachandran et al. (2017) stressed the variation in the survival ability of the bird species of some families under threatened environment.

The aquatic survey and analysis of river yemoji showed that a total of 28 fishes with 6 taxa belonging to 6 families were enumerated in the study area (Table 9). Tilapia with RD (50.0%), electric fish (14.29%) and catfish (10.71%) had the highest population in the river. Tilapia fish was the dominant species in the wetlands of the study area. These findings correspond with the report of Kundu et al. (2021) that tilapia fish is the predominant species in tropical wetlands landscapes. This may be due to the ability of this species to survive both anthropogenic and adverse environmental as well as their rapid reproductive ability. All the 6 families of the fish species encountered were equally prolific in the wetlands with 16.7% representation (Table 10). This conformed to the assertions of Dixon et al. (2016) who opined that tropical environment are

rich in fish species than other regions around the globe.

Table 5: Species Composition of Animals in Yemoji Wetlands

S/N	Name of Species	Family	F	RD(%)
1.	*Cercopithecus mona*	Cercopithecidae	4	8.16
2.	*Tragelaphus scriptus*	Bovidae	3	6.12
3.	*Tragelaphus sylvaticus*	Bovidae	1	2.04
4.	*Erethizon dorsalum*	Erethizontidae	4	8.16
5.	*Boa constrictor*	Boidae	1	2.04
6.	*Python molurus*	Pythonidae	1	2.04
7.	*Crocodylus niloticus*	Crocodylidae	3	6.12
8.	*Thryonomys swindarinus*	Thryonomyidae	6	12.24
9.	*Varanus niloticus*	Varanidae	2	4.08
10.	*Lutra Canadensis*	Mustelidae	1	2.04
11.	*Felis silvestris*	Felidae	2	4.08
12.	*Bitis gabonica*	Viperidae	3	6.12
13.	*Dendroaspis angusticeps*	Elapidae	2	4.08
14.	*Dendroaspis polylepis*	Elapidae	1	2.04
15.	*Smutsia temminckii*	Manidae	2	4.08
16.	*Glaucomys volans*	Sciuridae	3	6.12
17.	*Euxerus erythropus*	Sciuridae	2	4.08
18.	*Phacochoerus africanus*	Suidae	2	4.08
19.	*Cricetomys emini*	Nesomyidae	1	2.04
20.	*Viverra genetta*	Viverridae	2	4.08
21.	*Nerodia sipedon*	Colubridae	1	2.04
22.	*Testudo graeca*	Testudinidae	2	4.08

Table 6: Family Composition of Animals in Yemoji Wetlands

S/N	Family	Number of Species	Representation (%)
1	Cercopithecidae	1	4.5
2	Bovidae	2	9.1
3	Erethizontidae	1	4.5
4	Boidae	1	4.5
5	Pythonidae	1	4.5
6	Crocodylidae	1	4.5
7	Thryonomyidae	1	4.5
8	Varanidae	1	4.5
9	Mustelidae	1	4.5
10	Felidae	1	4.5
11	Viperidae	1	4.5
12	Elapidae	2	9.1
13	Manidae	1	4.5
14	Sciuridae	2	9.1
15	Suidae	1	4.5
16	Nesomyidae	1	4.5
17	Viverridae	1	4.5
18	Colubridae	1	4.5

19	Testudinidae	1	4.5

Table 7: Species Composition of Birds in Yemoji Wetlands

S/N	Name of Species	Family	F	RD(%)
1.	*Buteo jamaicensis*	Accipitridae	3	7.50
2.	*Bubo virginianus*	Strigidae	1	2.50
3.	*Cathartes aura*	Cathartidae	2	5.00
4.	*Harpia harpyja*	Accipitridae	1	2.50
5.	*Anas platyrhynchos*	Anatidae	3	7.50
6.	*Ardea alba*	Ardeidae	2	5.00
7.	*Corvus albus*	Corvidae	3	7.50
8.	*Francolinus bicalcaratus*	Phasianidae	5	12.50
9.	*Cinnyris asiaticus*	Nectariniidae	2	5.00
10.	*Zenaida asiatica*	Columbidae	2	5.00
11.	*Ciconia ciconia*	Ciconiidae	1	2.50
12.	*Picus viridis*	Picidae	2	5.00
13.	*Alcedo atthis*	Alcedinidae	1	2.50
14.	*Centropus sinensis*	Cuculidae	3	7.50
15.	*Milvus migrans*	Accipitridae	4	10.00
16.	*Anastomus lamelligerus*	Ciconiidae	1	2.50
17.	*Gallinago gallinago*	Scolopacidae	1	2.50
18.	*Scopus umbretta*	Scopidae	3	7.50

Table 8: Family Composition of Birds in Yemoji Wetlands

S/N	Family	Number of Species	Representation (%)
1	Accipitridae	3	16.7
2	Strigidae	1	5.6
3	Cathartidae	1	5.6
4	Anatidae	1	5.6
5	Ardeidae	1	5.6
6	Corvidae	1	5.6
7	Phasianidae	1	5.6
8	Nectariniidae	1	5.6
9	Columbidae	1	5.6
10	Ciconiidae	1	5.6
11	Picidae	1	5.6
12	Alcedinidae	1	5.6
13	Cuculidae	1	5.6
14	Ciconiidae	1	5.6
15	Scolopacidae	1	5.6
16	Scopidae	1	5.6

Table 9: Species Composition of Fish in Yemoji Wetlands

S/N	Name of Species	Family	F	RD(%)
1.	*Oreochromis niloticus*	Cichlidae	14	50.00
2.	*Clarias gariepinus*	Clariidae	3	10.71
3.	*Electrophorus electricus*	Gymnotidae	4	14.29
4.	*Squalus acanthias*	Squalidae	1	3.57
5.	*Labeo rohita*	Cyprinidae	4	14.29
6.	*Anguilla Anguilla*	Anguillidae	2	7.14

Table 10: Family composition of Fish in Yemoji Wetlands

S/N	Family	Number of Species	Representation (%)
1	Cichlidae	1	16.7
2	Clariidae	1	16.7
3	Gymnotidae	1	16.7
4	Squalidae	1	16.7
5	Cyprinidae	1	16.7
6	Anguillidae	1	16.7

4. CONCLUSION

Wetlands environments are havens for biodiversity and it is pertinent to protect them for sustainable ecosystem services and livelihood of the people around the area. They provide a stable breeding ground and food for flocks of migratory as well as residential birds in a region. Yemoji wetlands play a significant role in sustaining the biodiversity of the area as well as the livelihood of the people. This study is purposely to create awareness to the local people, conservation agencies and government to formulate necessary conservation strategies to preserve yemoji wetlands to maximise the ecosystem services and benefits to mankind. Also, conservation is necessary to preserve these biodiversity riched wetlands to militate against climate change and further degradation. The results of this study provide the datum empirical information for further studies on other biodiversity resources of yemoji wetlands. However, further studies are recommended to discover the soil biodiversity as well as detailed studies of the water bodies to increase the knowledge pool on yemoji wetlands.

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Sub-Theme No 4: Adaptive Silvicultural Practices for Climate Resilience and Forest Sustainability.

EFFECT OF BIOCHAR APPLICATION ON THE GROWTH PERFORMANCE OF *Annona senegalensis* pers SEEDLINGS

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ABSTRACT

The study was carried out to determine the effect of biochar application on the growth performance of *Annona senegalensis* seedlings at nursery stage. Seeds were sown in to germination box filled with river sand. The seedlings were transplanted at exactly two weeks into polythene pots filled with a mixture of soil with varying grams of biochar, which were left to blend for two weeks. There were five treatments, T_1 (5g of biochar), T_2 (10g of biochar), T_3 (15g of biochar), T_4 (20g of biochar) and T_5 (control). Complete randomized design was used for the experiment. Weekly measurement of the plant height, stem diameter and number of leaves were taken. Results showed that plants grown with T_2 had the highest mean plant height of 13.24cm, mean diameter of 0.37cm and mean number of leaves of 8.3. T_4 had the least mean height value of 12.15cm, while, T_0 had the least mean stem diameter value of 0.17cm and least mean number of leaves of 7.6.. Analysis of variance indicated that, the seedlings height were significant in all the treatments at six weeks with 0.0955 ($p<0.05$). Stem diameter were not significant with 0.7825 ($p<0.05$) at six weeks. Similarly, number of leaves were also significant with 0.0483 ($p<0.05$) at six weeks. At this level, 10g of biochar is recommended as a starter supplement in raising *Annona senegalensis* seedlings at nursery stage as against the use of inorganic fertilizer. Biochar may therefore be a useful soil amendment for commercial seedlings production of this medicinal tree species for plantation establishment.

Keywords: *Annona senegalensis*, Biochar, Nursery stage, Treatment, Medicinal.

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1.0 INTRODUCTION

Annona senegalensis, commonly known as African custard-apple. It is a species of flowering plant in the custard apple family, Annonaceae. A traditional food plant in Africa, the fruits of *A. senegalensis* have the potential to improve nutrition, boost food security, foster rural development and support sustainable land care. The wild custard apple is usually a multi-stemmed deciduous tree growing between 2 - 6 metres tall, but in favourable conditions, especially in east Africa, it can attain a height as much as 11 metres tall (WAC,2010). It is a multi-purpose tree species which provide food, medicine and a range of commodities for the local people. The plant is not generally cultivated, but is often gathered from the

wild (Uphof, 1959). The fruit is sometimes sold in local markets and this species is said to have the potential for domestication (Ruffo *et al*., 2002). The fruits are consumed raw with a nourishing taste. The edible white pulp of the ripe fruit has a pleasant, pineapple-like aroma with the flavour of apricots. The ripe fruit colour is usually yellow to orange which is around 5cm in diameter. The leaves are sometimes used as vegetables. The dried leaves contain 8.2% protein (NRC, 2008). The flowers are served as spice for various meals. The unopened flower buds are eaten in soups and used as flavouring in foods. This tree species are used for medicinal purposes in the rural areas. The bark of the tree is used for treating guinea worms and other worms, diarrhea, gastroenteritis, snakebite, toothache and respiratory infections, dermatological diseases and ophthalmic disorder (USDA, 2010; Idowu, 2009). The bark is chewed and smeared on fresh wounds. The bark and the roots are crushed together and applied to snakebite wounds (Ruffo *et al.,* 2002). Gum from the bark is used in sealing cuts and wounds. The leaves are used for treating pneumonia and as a tonic to promote general well being.

The roots are used in the treatment of stomach-ache, venereal diseases, chest colds and dizziness. In South Africa, roots are said to cure madness, and in Mozambique, they are fed to small children to induce them to forget the breast and thus hasten weaning (WAC, 2010). This study aimed to determine the effect of biochar application on the growth performance of this multipurpose species and to examine the potential of biochar as supplement for commercial seedlings production of this medicinal tree species for plantation establishment.

2.0 MATERIAL AND METHODS

2.1 Experimental Site

The experiment was carried out in the screen house of Federal College of Forestry, Ibadan. The college was located on Latitude 7^0 26'N and Longitude 3^0 15'E. The climate of the area is tropically dominated by an annual rainfall of about 1300-1500mm and average relative humidity of about 80%-85% with an average temperature of about 26^0C. The dry season, usually commence from November to March and the raining season from April to October (FRIN Metrological Station, 2014).

2.2 Materials and Method

The materials used for the experiment were *Annona senegalensis* seeds, river sand, germination boxes, top soil, polythene pots, watering can, pen, notebook (for taking growth readings), hand trowel, water, Biochar, ruler (for height measurement), Digital Vanier caliper (for diameter measurement), paper tape and Weighing balance. The seeds of *Annona senegalensis* were procured from Mokwa, Niger State and were later sown into the germination box filled with sterilized river sand. Watering was carried out once in a day (in the morning). The biochar used

were mixed in varying grams range of 5g, 10g, 15g and 20g with 2kg of top soil in the polythene pots and were allowed to decompose for 2 weeks before the seedlings were transplanted. However, germination of the seeds was completed within 8-10 days. Thus, the seedlings were pricked out and transplanted into the blended potting mixtures in the polythene pot according to the treatments and replicated seven times using Completely Randomized Design (CRD). The treatments were stated as follows: T_1- 5g biochar + 2kg of top soil; T_2-10g biochar + 2kg of top soil; T_3-15g biochar +2kg of top soil; T_4-20g biochar +2kg of top soil and T_0 - 2kg of topsoil (control).

2.3 Experimental Layout

Treatments	Replicates
T_1	T_1R_5, T_2R_6, T_3R_1, T_4R_6, T_2R_1, T_0R_1, T_4R_5
T_2	T_1R_2, T_1R_6, T_3R_2, T_4R_7, T_2R_2, T_0R_2, T_4R_4
T_3	T_1R_3, T_1R_7, T_3R_3, T_0R_7, T_2R_3, T_0R_3, T_4R_3
T_4	T_1R_2, T_0R_6, T_3R_4, T_3R_6, T_2R_4, T_0R_4, T_4R_2
T_0	T_1R_1, T_2R_7, T_3R_5, T_2R_5, T_2R_5, T_0R_5, T_4R_1

T- Treatment, R- Replicates

2.4 Variables Assessed in the Experiment

The following variables were assessed in the experiment;

1. Stem diameter (cm): the stem diameter of each seedling were measured with the aid of digital venier caliper
2. Seedling height (cm): it was measured with meter rule (cm).
3. Number of leaves: This was achieved by enumeration of the leaves on each seedling.

3.0 DATA ANALYSIS

The data were subjected to Analysis of Variance (ANOVA) using SPSS. Mean separation where applicable were carried out using Fisher's Least Significant Difference (LSD). Descriptive statistical tool such as graph was also employed to show the trend of growth performance of the seedlings over time.

4.0 RESULT AND DISCUSSION

Analysis of Variance for Seedlings Height of *Annona senegalensis* Seedlings at Six Weeks

Table1 showed that there were significant differences ($p < 0.05$) in the effect of the treatment on the seedlings height at 6 weeks. This may be due to gradual release of nutrients in the biochar to the plants at this stage (Badimo *et al.,* 2011).

Table 1: Analysis of Variance for Height of *Annona senegalensis* Seedlings

Variable	S.V	D.F	S.S	M.S	F.	P. value
Height	Treatment	4	8.91646	1.84524	3.3744	0.0955 **
	Error	30	26.82318	0.94823		
	Total	34	34.65185			

Analysis of Variance for Stem Diameter of *Annona senegalensis* Seedlings at Six Weeks

There were no significant differences ($p < 0.05$) in the effect of biochar on the stem diameter as indicated in Table 2 at the sixth week. This may be ascribed to completion among the seedlings for light and nutrients.

Table 2: Analysis of Variance for Stem Diameter of *Annona senegalensis* Seedlings

Variable	S.V	D.F	S.S	M.S	F.	Sig
Stem Diameter	Treatment	4	1.51946	0.53624	0.46546	0.7825 ns
	Error	30	39.94603	1.48413		
	Total	34	40.37482			

Analysis of Variance for Number of Leaves of *Annona senegalensis* Seedlings at Six Weeks

The leaf production analysis in Table 3 indicated that, there were significant differences ($p < 0.05$) in the effect of the biochar on the leaf production of *A. senegalensis* seedlings at the sixth week. This may be due to the prompt release of the nutrients in the biochar to the seedlings at this level.

Table 3: Analysis of Variance for Number of Leaves of *Annona senegalensis* Seedlings

Variable	S.V	D.F	S.S	M.S	F.	Sig
Leaf Production	Treatment	4	3.73524	0.85275	3.4181	0.0483**
	Error	30	7.88032	0.38862		
	Total	34	13.94775			

Mean Separation of the Variables of *Annona senegalensis* Seedlings at Six Weeks

Table 4: Mean Separation of Plant Height, Stem Diameter and Number of Leaves for Seedlings of *A. senegalensis*

Treatment	Number of Leaves	Height (CM)	Stem Diameter (CM)
T0	7.6b	12.78ab	0.17bc
T1	7.7c	12.78ab	0.19ab
T2	8.3a	13.24a	0.37a
T3	7.8ab	12.18b	0.27b
T4	7.8ab	12.15c	0.27b

Mean Separation of the Number of Leaves of Annona senegalensis Seedlings at Six Weeks

The mean separation analysis of the number of leaves (Table 4 and Figure 1) indicated that, T_2 had the highest number of leaves and were significantly different from other treatments with a mean of 8.3 followed closely by T_3 and T_4 with mean value of 7.8 respectively. While, T_0 had the least mean as compare with other seedlings in number of leaves with 7.6.

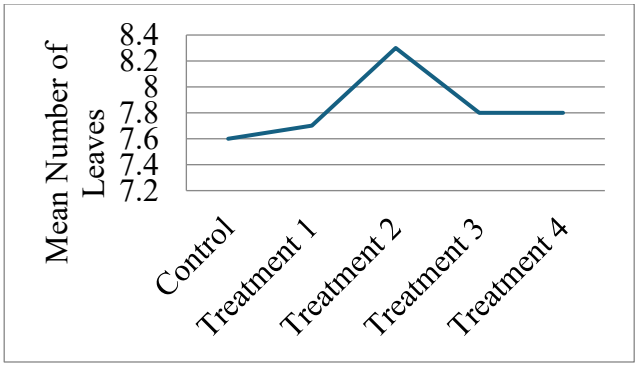

Figure 1: Leaf production trends of *A. senegalensis* seedlings at six weeks

Mean Separation of the Height of *Annona senegalensis* Seedlings at Six Weeks

Table 4 and Figure 2 reveals that T_2 performed better in height development with 13.24cm followed byT_1 and T_0 with 12.78cm. While, T_4 had the least height with an average of 12.15cm at the sixth week of growth.

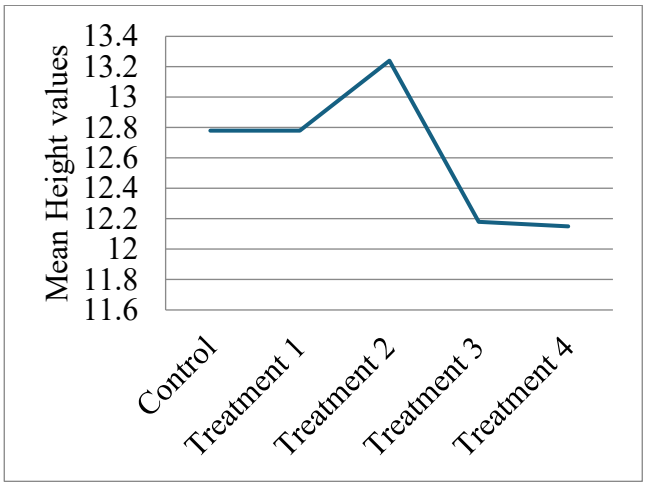

Figure 2: Height trends of *Annona senegalensis* Seedlings at Six Weeks

Mean Separation of the Stem Diameter of *Annona senegalensis* Seedlings at Six Weeks

The mean separation of the stem diameter values as presented in Table 4 and Figure 3, it was evident that T_2 had the highest performance in terms of stem diameter with a mean value of 0.26cm, followed by T_3 and T_4 with a mean diameter of 0.27cm respectively. While, T_0 had the least mean stem diameter of 0.17cm.

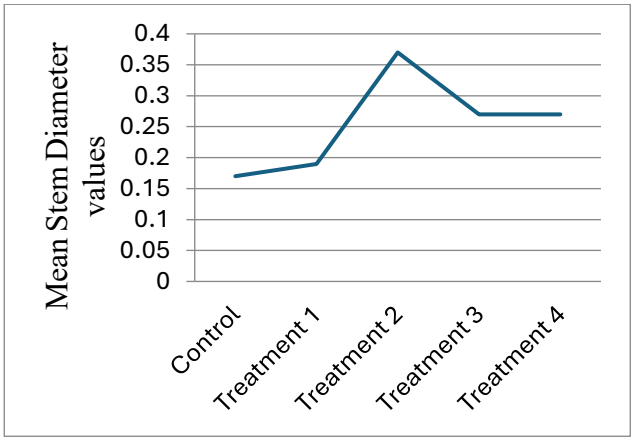

Figure 3: Stem diameter trends of *Annona senegalensis* seedlings at six weeks

5.0 DISCUSSION

Biochar is a carbon-rich product defined as a solid material obtained from the thermochemical conversion of biomass in an oxygen limited environment (IBI,2012). It has been proved to be a soil amendment that promotes the growth and productivity of arable crops and tree species.

Biederman and Harpola (2013) reported that biochar had a significant effect on plant productivity and nutrient cycling. Similar result was also recorded by Jeffery *et al.* (2011) when biochar was used as a soil amendment for maize and lettuce on the same farmland. High biomass production and yield were observed per acre in the cropping season. The results derived from this study attested a positive significant effect of biochar on the growth performance of *Annona Senegalensis* which agrees with the findings of chan and xu (2009).

They recorded that biochar nutrient enhances the growth of cowpea and yield per acre on the field. Biochar release adequate nutrient into the soil for easy absorption by plant with consequential increase in physiological and morphological processes resulting in high productivity (Jeffery *et al.* 2011). This is contrary to the result of wisnobroto *et al*.(2010), who reported a negative response of Alfalfa plant to biochar as soil amendment.

Bonanomi *et al*. (2016) opined that organic farming with biochar induces positive changes in soil microbiota that affects agroecosystem functions. Biochar promotes the growth performance of *Annona Senegalensis* at six weeks with positive significant effects on the height and leaf production that is number of leaves. Research has also revealed that biochar has numerous positive impacts on the health of plants and the environment. Bonanomi *et al.* (2015) recorded that biochar as a soil amendment has a potential for controlling plant diseases. While, Chan and Xu (2009) attested that biochar is a potential supplement for soil stability and environmental management. Biochar is currently used in an unlimited way as a soil amendment and commercialized around the world (Jirka and Tomilinson, 2015).

6.0 CONCLUSION

From the results, it could be concluded that biochar had a great effects on the growth performance of *Annona senegalensis* seedlings at juvenile stage as compared with other conventional manure used for seedling production. Hence, 10g of biochar is recommended as a starter supplement in raising *Annona senegalensis* seedlings at nursery stage as against the use of inorganic fertilizer with inherent adverse effects on the environment. Biochar may therefore be a useful soil amendment for commercial seedlings production of this medicinal tree species for plantation establishment. More research activities should also be intensified on the use of biochar for the

production of other economic tree species seedlings for conservation and sustainable management.

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CONTRIBUTIONS OF AGROFORESTRY SYSTEMS TO FOOD SECURITY AND CLIMATE RESILIENCE IN NIGERIA: A REVIEW

SUB THEME: INTEGRATING AGROFORESTRY SYSTEMS FOR FOOD SECURITY AND CLIMATE ADAPTATION

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Abstract

This review explores the contributions of agroforestry systems to food security and climate resilience in Nigeria. Agroforestry system integrates trees, crops, and livestock to enhance agricultural sustainability, mitigate climate risks, and improve rural livelihoods. The study examines the impact of different agroforestry systems on food security, their role in carbon sequestration & climate resilience, as well as their ability to enhance ecosystem services. Recent noticeable improvement in food production and drops in food inflation across the length and breadth of the country also corroborated the contributions of Agroforestry to food security and economic growth. Income generated through various Agroforestry system practices in Nigeria has given farmers leverages over relative poverty and also the ability to afford essential household needs while maintaining food security, life on the land, healthcare, and sanitation. In the same vein, Agroforestry provides exceptional influence and resilience to farmers ability to control soil erosion and sustainable ecological stability through integration of trees and shrubs with crops and livestock that enhances productivity, sustainability, and environmental resilience.

However, despite its benefits, agroforestry adoption in Nigeria faces array of challenges which including policy gaps, land tenure issues, and limited farmers' education and awareness. The review finally concludes with policy recommendations to promote agroforestry as a sustainable agricultural and food security strategy, and also as a tool for climate resilience.

Keywords: Agroforestry, Agroforestry Systems, Food Security, Climate Resilience

INTRODUCTION

Nigeria's efforts and reliance on Agriculture as a means for food security is justifiable. As one of the Africa most populous countries globally, Agriculture is said to accounts for about 20% of the country's Gross Domestic Product (GDP) (Adamaagashi *et al.,* 2023). The sector is also known as the major employer of a huge workforce from amongst its population, particularly in rural areas, where farming is known as the primary occupation and the only source of livelihood. However, the sector is

highly vulnerable to the impacts of climate change, including erratic rainfall patterns, temperature extremes, increased pests and diseases, soil degradation, economic downturn such as inflation, government policies such as fiscal reforms among others (Adamaagashi *et al.,* 2023).

More often than not, the increasing impacts of climate change on agriculture necessitate the development of systems that are both resilient and sustainable (Pancholi *et al.,* 2023). Climate resilience in agriculture refers to the ability of the system to absorb shocks and stresses caused by climatic changes without any dire effect on its core function (Altieri *et al.,* 2015; Pancholi *et al.,* 2023). In a broader term, it involves adopting practices that reduce the environmental footprint of agriculture, such as reducing water use and greenhouse gas emissions, while simultaneously enhancing its resilience to climatic shocks (Altieri and Nicholls, 2017). Agroforestry system practices stand as an important approach to this due to its ability to balance the advantages of the economy, society, and environment. Agroforestry is recognized as the foremost land-use choice for safeguarding ecology while satisfying the basic needs of the majority of society (Akhter *et al.,* 2022).

Agroforestry is an emblematic agricultural model that combines production of trees and plants export products such as rubber, clove, timber, cocoa, cashew, sesame seeds, resin among others with ecosystems services, such as carbon capture. It is practically the most rewarding system in terms of economic, social, and environmental sustainability (Udawatta *et al.,* 2019). Agroforestry practices have the ability to provides a range of technical solutions with significative impact on farmers' incomes, countries' exports, contribution to national richness, as well as improved well-being. Agroforestry patterns display a wide gradient from re-introducing diversity in complex cropping systems (intercropping/tree associations) to forest management and Non-Timber Forest Products (NTFPs) gathering (Cialdella *et al.,* 2023).

Additionally, it provides access to high capital and plant diversity such as cocoa, pineapple, turmeric, and ginger among others which significantly increases income to rural farmers, and provides habitat, feeding, and breeding space to wildlife (Kabir and Webb, 2008; Miah and Hussain, 2019). Given the rising demand for energy (fuelwood), fruits, and timber conditioned by the rising population, a suitable approach to bridge a market gap and satisfy population needs remain agroforestry system (Kibria and Saha, 2011). Through Agroforestry, the multifunctionality of annual/perennial intercropping with trees has been demonstrated to help diversify sources of income, provide bioenergy, shade for pasture and animals, wind, soil and water protection (Cialdella *et al.,* 2023). However, dissemination of the benefits of agroforestry still faces path dependency in innovation processes (van Noordwijk, 2021; Martin *et al.,* 2022). Agroforestry systems still

lack of both economic and technical field realities, as well as a better understanding of farmers' practices, strategies and perceptions. Although agroforestry has been practiced for millennia, it remains a relatively young and widely open field of research due to the importance of the context in which agroforestry practices are developed (Cialdella *et al.,* 2023).

Furthermore, climate change affects several aspects of livelihood, which includes food security, environment degradation and poverty. Climate change and its variability are significant drivers of the global rise in hunger (FAO *et al.,* 2018). Food security is indispensable to survival, while food insecurity is a reflection of a dysfunctional food system (Capone *et al.,* 2019; El Bilali *et al.,* 2020). Food security address's goal 2 and 3 of sustainable development goals (SDGs), which is zero hunger and good health and mental wellbeing. Achieving food and nutrition security has remained a major health challenge in developing countries, particularly in regions like SSA (Adesete *et al.,* 2022).

Food security consist of four major dimensions/or elements namely: availability, accessibility/affordability, utilization and sustainability**.** While food availability reflects the physical presence of food; food access implies the ability to acquire food in the right proportion; food utilization indicates food sufficiency in both quality and quantity and sustainability refers to the uninterrupted access at all times to food ((Food and Agricultural Organisation) FAO, 2006; Titus and Adetokunbo, 2007; Adesete *et al.,* 2022).

The FAO also identifies population growth as a critical determinant of food security (FAO, 2009; FAO, 2013). It is therefore not surprising that with the observed large increases in the country's population, Nigeria faces a crisis in terms of access to food and general food availability. Currently, according to statistics from the Intelligence Unit of The Economist, Nigeria is ranked at 38 out of 100 according to its food security status (Owoo, 2020).

Similarly, statistics have shown that the annual population growth rates in Nigeria between 2011 and 2024 averaged 2.57%, while the annual growth rate of agriculture between the period of 2011 and 2020 averaged 3.38% (Macrotrends, 2024; IndexMundi, 2024), suggesting that the real indicators of food security in Nigeria are economic access and per capita real income of households. Unfortunately, the engagement and the occupation of about two-third of households in the south of the Sahara including Nigeria have suffered from these and rendered many into vulnerable Agricultural practice as the region purchasing power continues to dwindle in the face of harsh economic realities (FAO, IFAD and WFP, 2015). In the face of persistent and sharp increase in food prices, low demand for wage labor, unemployment, sickness or death of bread-winner, existence of adequate aggregate food supplies does not guarantee food security at the household level (Kakwani and Son, 2017).

Despite Nigeria having achieved a reduction in undernourishment of the population by more than half, from 19.3% in 1990 to 8.5% in 2010 to 2012, the number of people who are undernourished increased from approximately 10 million people in 2010 to about 14 million by 2016 (FAO 2017), with more severe conditions observed in the conflict-prone north-eastern zone of the country. In addition to differences by geographical zones, there are also rural/urban, and cultural variations in food security across the country (Owoo, 2020).

Against this backdrop, Agroforestry holds a great potential for food security and the sequestration of carbon both below and above ground because it combines perennial trees and/or shrubs with annual or perennial agronomic crops. Despite not being primarily intended for carbon sequestration, agroforestry systems have been shown to offer a special chance to enhance the amount of carbon in the terrestrial biosphere (Kisaka *et al.,* 2023; Maitra *et al.,* 2024), stating that agroforestry has the potential to boost soil carbon stocks and eventually to preserve biodiversity. Additionally, agroforestry systems offer an extra benefit by providing a variety of products and thereby mitigate the climate change impact by conserving biodiversity, raising carbon stocks, increasing forest cover area, and lowering farmer risk (Lasco *et al.,* 2014; Gitari *et al.,* 2024).

Agroforestry systems primarily rely on productivity mechanisms of increased carbon storage in nearby soils through photosynthesis in the tissue of woody plants and lower atmospheric concentrations of greenhouse gases (GHGs) (Padovan *et al.,* 2015; Gitari *et al.,* 2024). Additionally, by increasing farmland resilience through output diversification and ecological ecosystem services, agroforestry can assist farmers in adapting to climate change (Quandt, 2020). Agroforestry also offers the benefit when crop failure occurs due to erratic weather, by allowing the farmers to access tree crops and reduce financial risk (Pello *et al.,* 2021). Taking into account the current food insecurity and climate risk, farmers in vulnerable areas have the need to adopt a variety of agroforestry systems as climate change mitigation strategies.

By and large, the Implementation of agroforestry system would support farmers resilience to withstand the turbulence of climate change, low food production, farm produce loss due to the effect of climate on storage and also provide for the options of income diversification and food security.

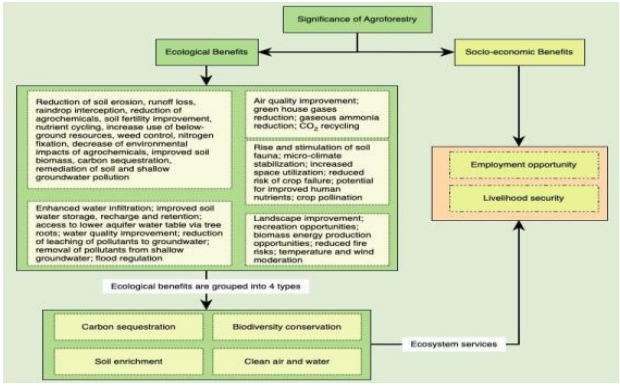

Figure. 1. Significance of agroforestry systems (Atreya *et al.,* 2021).

2.0 Agroforestry Systems and Impacts on Food Security in Nigeria

Compared to other agricultural systems, investment in agroforestry generates proportionately more income and benefits to farmers with small amounts of land. This income enables them to pay for essential household needs while maintaining food security, life on the land, healthcare, and sanitation, which lowers relative poverty (Kibria and Saha, 2011; Misbahuzzaman, 2016).

Similarly, Agroforestry is arguably one of the workable land management strategies that encourage ecological stability, increase productivity, and support environmentally sound development (Ajake, 2012; Cherubin *et al.,* 2018). Including trees in the farming system could not only provide wood, food, and/or animal products but also greatly lessen the environmental footprint (Sairam *et al.,* 2023).

In Nigeria, the Age long farmers who practiced the shifting cultivation system were predominantly agro-foresters. These farmers combined planting of different trees and crops for which they had defined roles such as soil erosion reduction and increased productivity on their farmlands for the benefit of mankind. For instance, *Irvingia spp* (Oro in Yoruba and Ogbono in south/east) was left on farmlands because of its use as food and as condiments, while *Chrysophylum albidum* (Agbalumo in Yoruba) and *Dacryodes edulis* (Ube in Igbo) were also left on farmlands for their food value. The *Parkia spp* (dawadawa in Hausa) in Northern Nigeria was preserved and is still preserved by farmers for its value as condiment. *Acacia Senegal* was preserved for gum Arabic and for soil fertility. *Militia excelsa* (Iroko in Yoruba) was left for its wood and cultural values. All these trees mentioned and some other trees were always allowed to grow with various food crops (maize, cassava, melon, pepper, sorghum, cocoyam, banana, plantain among others) on farmlands. Animals were supported in the system by free range, while Fulanis were known to graze their animals in such systems during which the animals browse on the fields for nutrition uptake (Otiwa *et al.,* 2023).

The agroforestry systems in Nigeria also encompass a diverse range of practices that integrate trees and shrubs with crops and livestock to enhance productivity, sustainability, and environmental resilience. The systems are explained as thus;

2.1 *Agrisilvicultural System* (Trees combined with crops)

In Agri-silvicultural system, there are combination of crops and trees in the same farming system. This method allows farmers to benefit from the advantages of both agricultural and forestry practices, thereby enhancing soil fertility, reducing erosion, and increasing biodiversity within the farm landscape (Amonum *et al.,* 2009; Alao and Shuaibu, 2013). Similarly, this system could either be in the form of home garden, alley cropping, taungya, improved fallow, multilayer tree garden, multipurpose trees on cropland,

plantation crop combination, trees in soil conservation and reclamation, shelterbelts, windbreaks and live hedges, and fuelwood production (Adeyemi *et al.,* 2020).

2.2 *Silvopastoral System* (Trees and pastures or animals)

Silvopastoral systems integrate trees with pasture and livestock. This approach improves the sustainability of livestock farming by providing shade and shelter for animals while utilizing tree fodder, thereby increasing overall productivity (Amonum *et al.,* 2009). This could either be in the form of trees on rangeland or pasture, plantation crops with pastures and animals, and protein banks.

2.3 *Agrosilvopastoral Systems* (Animals, trees and crops)

Agro-silvopastoral systems combine crops, trees, and animals/livestock within the same farming space. In this integrated approach, there is a guarantee for land use efficiency and maximization. The system also provides higher opportunity of economic returns to farmers through production diversification. This system could be practiced in the home garden via animals rearing alongside multipurpose woody hedgerows, apiculture with trees, and aqua-forestry (Otiwa *et al.,* 2023).

2.4 Taungya System

The Taungya system is a traditional agroforestry practice that merges crop cultivation with forest management. In this system, farmers plant food crops alongside young trees to provide mutual benefits. After allowing the crops to thrive in the initial years of the trees' growth, the forestry department assumes management of the land for the trees' continued growth.

Other Agroforestry systems include alley cropping, live fences, improved fallows, windbreakers, and shelterbelts. Alley cropping for instance, adopts planting food crops between rows of trees, which can be pruned regularly to optimize light and nutrients for the crops. These practices collectively contribute to environmental conservation, increased crop yields, and enhanced food security across the regions in Nigeria (Olatujoye *et al.,* 2025).

By and large, thorough implementation and expansion of these agroforestry systems in Nigeria has the potential of providing sustainable solutions to some of the country’s agricultural challenges, such as land degradation and food insecurity.

2.5 Regional Variations of Agroforestry Practices in Nigeria

Agroforestry practices in Nigeria exhibit significant regional variations, influenced by the country's diverse ecological zones and farming traditions. Each region's specific climate, soil types, and cultural practices dictate the agroforestry systems adopted by farmers.

2.5.1 Agroforestry Systems in Northern Nigeria

In the semi-arid zones of Northern Nigeria, traditional agroforestry systems, such as mixed farming, are commonly practiced. Farmers integrate crops with trees to enhance soil fertility and provide shade for crops, particularly in areas

with harsh climatic conditions (Zomer *et al.,* 2009). Notable agroforestry practices include shifting cultivation and the use of shelterbelts to combat soil erosion and wind damage (Lelamo, 2021). The preferred tree species in this region often include multipurpose trees such as *Azadirachta indica* (Neem) and *Eucalyptus camaldulensis* (River red gum), which serve various functions for man (medicine), fodder for livestock, and also for soil health improvement (Oke and Odebiyi, 2007).

2.5.2 Agroforestry Systems in Southern Nigeria

Conversely, Southern Nigeria, particularly in humid areas, showcases a variety of agroforestry systems with the most dominant system centered around cocoa cultivation. Cocoa agroforests represent a common practice where forest trees are intercropped with cocoa plants to provide shade and other environmental benefits. The rich biodiversity in this region allows farmers to select from numerous tree species available (Ibrahim and Mohammed, 2014). Research indicates that a mix of over 25 indigenous tree and shrub species is commonly utilized, contributing to both agricultural productivity and ecological sustainability (Umeh, 2011).

2.5.3 Agroforestry Systems in Nigeria's Highland Regions

In the highland areas of Nigeria such as Jos and Taraba, farmers exhibit a preference for specific tree species, which play a crucial role in the agroforestry systems. Studies show that farmers highly value species like the locust bean due to its multiple uses (Ibrahim and Mohammed, 2014). Generally, the agroforestry systems are characterized by the integration of diverse species that not only provide shade and shelter for crops but also enhance the overall resilience of the agricultural systems to climatic variability across regions.

3.0 Impact of Climate change on food security in Nigeria

Nigeria, like many sub-Saharan African countries, is susceptible to the impacts of changing climatic conditions. Researchers such as Ayinde *et al.* (2011), Ughaelu (2017), and Ikem (2018) have observed that recurrent environmental disasters in Nigeria have contributed to decreased food productivity and increased human suffering over the past decade. Notably, in 2012, Nigeria experienced severe flooding, unprecedented in the previous forty years, which resulted in substantial loss of human lives, crops, livestock, and displacement of people (Ogbuchi, 2020). The effects of climate change vary across Nigeria's six vegetative zones, as highlighted by Ughaelu (2017). The semi-arid Sudan and arid Sahel Savannah region face reduced rainfall, droughts, and increased desertification. The Northern and Southern Guinea savannah belt witness changes in rainfall patterns, including delayed onset and an extended dry season. Areas along the coastlines frequently suffer from severe flooding during the rainy season (Ikem, 2018). In the Rain Forest zone, climate change results in delayed rainfall onset, prolonged dry seasons,

heat waves, and increased coastal flooding. The Mangrove Swamp experiences the flooding of typically dry plains, as well as rising sea levels that pose risks to farming activities (Berhanu and Wolde, 2019).

The impact of climate change on agricultural productivity in Nigeria has resulted in the deterioration of affected areas, rendering them unsuitable for crop and animal production. This has been attributed to the utilization of natural resources (Wossen *et al.,* 2018). Additionally, the persistent flooding of coastlines and the southern parts of Nigeria have caused damage to crops, loss of soil fertility, soil toxicity, and disruption of the soil ecosystem (Wossen *et al.,* 2018). Concerns regarding the impact of climate change on sustainable food production in Nigeria have been highlighted by the World Bank and the Food and Agricultural Organization in their respective publications (World Bank, 2016; FAO, 2017).

Numerous research findings indicate that the varying climatic conditions caused by climate change have significantly affected agricultural productivity in Nigeria, leading to reduced output. As a result, there has been a shortage of food supply and increased food prices. The prevalence of food insecurity is escalating in Nigeria due to climatic factors that have limited agricultural productivity. Despite the weather forecast for the year 2025 predicting rainfall as early as March, many ecological zones are yet to experience expected rainfall needed to set into motion the planting for the rainy season (Nigerian Meteorological Agency (NiMet), 2025).

Similarly, Alterations induced by climate change, such as droughts, heavy precipitation, flooding, rising temperatures, increased aridity and soil acidity, changes in relative humidity, and higher evaporation rates, have adverse effects on agricultural productivity and food systems in Nigeria. Adishi and Oluka (2018) observe that climate change has become a daily reality in Nigeria, with environmental issues such as flooding, droughts, rising temperatures, and extreme weather events increasingly disrupting agricultural activities.

Fanifosi *et al.,* (2024) examined the impact of climatic parameter changes such as precipitation, relative humidity, and temperature anomaly on food insecurity, controlling for sub-national HDI and drought in Nigeria using a time series data from 2003 to 2023. Fanifosi and others confirms the high impact of climate change on food productivity and security both in the short and long term, supporting previous similar investigations. By and large, the threat posed by climate change to agricultural production and food security in Nigeria cannot be overemphasized.

3.1 Agroforestry Practices' Contribution to Climate Change Resilience via Carbon Sequestration

Agroforestry contributes to weather exchange mitigation in three approaches, which include sequestering carbon in biomass and soils, lowering GHG emissions, and warding off

emissions via decreased fossil gas and power utilization on farms.

Agroforestry strategies can reduce GHG emissions by increasing carbon storage in the above ground and below ground biomass and soil organic carbon stocks (IPCC, 2019). Agroforestry integrated with crop and livestock systems can significantly increase carbon sequestration. Human activities lead to burning of fossil fuels and coal and destruction of forests, all of which contribute to global climate change (Ripple *et al.,* 2020).

However, Agricultural practices such as conservation tillage, grassland management, and in-crop grazing can also help reduce carbon losses and improve carbon storage on agricultural land. Soil carbon sequestration is an important ecological service provided by grasslands and can be enhanced by optimal grazing strategies (Griscom *et al.,* 2017).

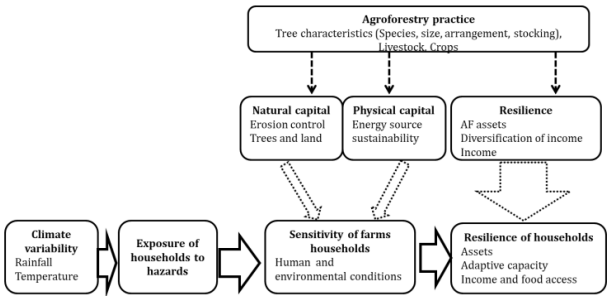

Fig. 2: The research's conceptual framework explaining farmers' vulnerability to the consequences of climate variability (Turner *et al.,* 2003; Modified by Mabel Nabunya, 2017).

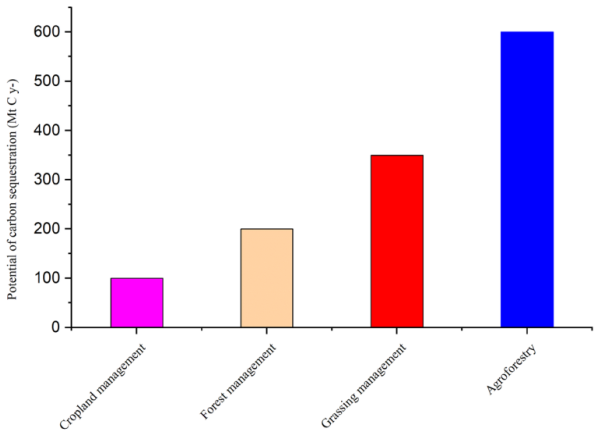

Fig. 3: Carbon sequestration potential from different land-use systems (Yohannes, 2016).

3.2 Roles of Agroforestry on Microclimate Regulation and Biodiversity Conservation

Trees planting could encourage the development of microclimates favorable for crop growth and improved mineral recycling, resulting in a larger ground cover that could lessen soil erosion and moderate extreme temperature (Amadi *et al.,* 2013; Nyawade *et al.,* 2020; Purnama *et al.,* 2022). Also, agroforestry contributes to the decrease of atmospheric carbon dioxide concentration, which causes local and global climate change.

Trees can enhance microclimates by lowering wind speeds and offering shade, both of which are important for crop survival in extreme weather conditions (Jaman *et al.,* 2021). Furthermore, many agroforestry systems have trees with deep roots that allow them to reach deeper soil layers for water, which serves as a supply of water during dry spells (Udawatta *et al.,* 2019). Agroforestry provides farmers and communities with many options to adapt to the changing climate. Agroforestry helps to

diversify farm output and lower the risk of crop failure from extreme weather (Jaman *et al.,* 2021). Agroforestry protects the environment of the surrounding areas by reducing soil erosion and soil nutrient depletion, decreasing bare land through tree cover, thereby contributing to biodiversity conservation (Alam and Sarker, 2011).

4.0 Challenges and Barriers to Agroforestry Adoption in Nigeria

Despite the numerous benefits of agroforestry, several challenges hinder its widespread adoption in Nigeria:

i. **Land Tenure Issues:** Many farmers lack secure land ownership, discouraging long-term investments in tree planting. Insecure land tenure also leads to disputes and reluctance to implement agroforestry practices (Obi-Egbedi, 2022).

ii. **Policy and Institutional Barriers:** The absence of well-defined agroforestry policies and lack of institutional support slow adoption. Government initiatives often prioritize monoculture farming, neglecting agroforestry's benefits (Akinkuolie *et al.,* 2025).

iii. **Limited Awareness and Training:** Many farmers are unaware of agroforestry's advantages, and inadequate extension services hinder knowledge dissemination. Training programs on agroforestry management are limited (Arowosegbe *et al.,*2024).

iv. **High Initial Costs and Limited Financial Support:** Establishing agroforestry systems requires initial investment in tree seedlings, labor, and land preparation. The lack of financial incentives and credit access further discourages adoption (Oladele *et al.,* 2020).

v. **Market Constraints:** Agroforestry products such as timber, fruits, and medicinal plants require stable markets. Poor market access and fluctuating prices make farmers hesitant to engage in agroforestry.

vi. **Climate Change and Environmental Factors:** Unpredictable weather patterns, prolonged droughts, and pest infestations threaten the success of agroforestry systems (Ashiegbu *et al.,* 2024).

5.0 Policy Recommendations

Addressing these challenges requires comprehensive policies, farmer education, financial support, and institutional collaboration to promote agroforestry in Nigeria.

By and large, to enhance widespread adoption of agroforestry systems in Nigeria, there is a need to put in place policies that guarantees land security for agroforestry practitioners. In the same vein, there is an urgent need for investment in research and extension services for sustainable agroforestry practices. Lastly, farmers and Agro foresters should be given

access to financial incentives and subsidies to encourage agroforestry investments.

6.0 Conclusion

Agroforestry presents a viable solution for addressing food insecurity, economic instability through the provision of income alternatives and production diversification, and climate resilience in Nigeria through carbon sequestration, water usage reduction, and greenhouse gas emissions. Despite challenges, its potential benefits necessitate policy interventions and farmer support programs. Future research should focus on evaluating the long-term impacts of agroforestry on rural livelihoods and environmental sustainability.

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Sawn timber utilization in the Nigerian-based wood industry: Current Status, Crises, and the Potential of Solar Kiln Technology

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Abstract

Efficient wood drying is crucial for enhancing the performance and longevity of wood products. The wood drying industry is one of the most vital sectors in the wood products manufacturing industries. However, it is unfortunate that the wood drying industry in Nigeria remains lethargic and grossly ineffective. Despite the abundance of timber resources, there is low preference for efficient wood drying facilities which results into poor reputation of sawn timber for structural applications and other end uses. Apart from open-air drying which is commonly known in Nigeria, improper practices- such as end racking and utilization of unseasoned timber are often adopted among small- and medium-scale timber products manufacturers. These procedures compromise wood products quality, reduce durability, and limit structural integrity. Furthermore, existing conventional kiln facilities are limited and often operate below capacity due to high energy costs, unreliable power supply, and insufficient investment. As an option, wood products manufacturers in Nigeria are resorting to utilization of Medium Density Fiberboard (MDF) for various structural and construction applications. However, utilization of MDF undermines the relevance of solid (round) wood as a raw material. This paper examines current status of Nigeria's wood drying sector, associated challenges, and potential of solar kiln drying technology as a sustainable alternative. Solar energy presents an eco-friendly, cost-effective, and widely accessible resource for improving timber drying efficiency and promoting the broader utilization of solid wood in construction and manufacturing. This review aims to inform stakeholders and policymakers on viable strategies for strengthening the timber processing industry in Nigeria.

Keywords: wood seasoning, solar kiln, timber utilization, renewable energy, Nigeria wood processing industry

1. Introduction

Timber remains one of the most versatile and widely utilized natural resources, with applications spanning construction, furniture, and various industrial products (Bauer, 2003). Derived from both natural and plantation forests, timber continues to be a vital raw material for domestic and commercial use (Ekundayo *et al*., 2021). From 2011 to 2015, Nigeria exported $400.2 million worth of timber. This value is below that of Cameroun and Gabon who exported $745.9 million and $474.7 million worth of timber,

respectively. Timber exports do not only earn foreign exchange but also socio-economic development (Idumah *et al*., 2016). Olorunnisola (2022) submitted that about 80% of sawn timber production is consumed annually by the building industry in Nigeria. Wood-based products are commonly found in homes, offices, religious centers, and public spaces, serving as essential components in furniture such as desks, tables, chairs, cabinets, and wardrobes (Ohagwu & Ugwuishiwu, 2011; Ogunwusi, 2012).

Despite its widespread utility, the performance and durability of timber products are contingent upon appropriate processing techniques. One of the most critical procedures in this regard is wood drying or seasoning, which significantly enhances dimensional stability, strength, workability, and resistance to biodegradation (Moya *et al*., 2012; Korkut *et al*., 2018; Femi-Ibirogba, 2021). Properly seasoned timber is easier to transport and handle, demonstrates improved bonding with adhesives, and offers greater longevity in structural applications. However, in Nigeria, the emphasis on wood drying within the timber processing and manufacturing sector remains inadequate. Documentation on commercial wood drying practices is limited, and many existing kiln facilities are either non-functional or operating below capacity (Ogunwusi, 2012). Government policies, inconsistent energy supply, and high operational costs have contributed to the stagnation of this critical subsector (Arowosoge *et al*., 2010; Femi-Ibirogba, 2021). As a result, the reliance on unseasoned or poorly seasoned timber persists, diminishing the structural reliability of wood products and undermining the role of timber as a primary material in construction (Langdon *et al*., 2021).

Given these challenges, this study assesses the sawn timber utilization in the Nigerian-based wood industry as it relates to current status of the wood drying industry in Nigeria. The study further identifies critical barriers to development in wood industry and evaluates the potential of solar kiln technology as a sustainable and potentially viable solution. Solar drying offers an environmentally friendly option of timber drying, leveraging Nigeria's abundant solar radiation to improve timber processing outcomes. This review aims to inform industry stakeholders and policymakers on the practical interventions that could revitalize the wood drying sector and enhance the overall quality and competitiveness of Nigerian wood products.

2. Contextual Overview of Nigeria's Wood Drying Industry

2.1 Present Status

Timber processing and wood products manufacturing constitute vital industrial activities in Nigeria-based wood industry (Ogunwusi, 2012). However, the sub-sector responsible for sawn timber drying remains poorly developed and insufficiently documented (Ashkin, 2013; Femi-

Ibirogba, 2021). A recent field survey (Amoo-Onidundu *et al*., 2023) indicated that only a handful of timber drying facilities are currently operational, and even fewer are functioning at full capacity. Table 1 summarizes key facilities known to be in operation and their respective statuses.

The limited operational capacity of these facilities reflects deeper systemic issues, including inadequate investment, lack of awareness, outdated infrastructure, and an absence of supportive policy frameworks. Consequently, many small- and medium-scale manufacturers rely on rudimentary drying techniques such as air drying or sun drying, which are time-consuming and often ineffective in ensuring consistent wood quality. These practices significantly compromise the structural integrity and service life of wood-based products.

Table 1*:* Operational status of Wood Drying Facilities in Southwestern Nigeria

Wood drying plant in Nigeria	Location address	Capacity of kiln	Remark
Forestry Research Institute of Nigeria (FRIN)	Idi-Ishin Area, Ibadan, Oyo-State	About 500 ft^3	currently running skeletal production
Timber Treat Ltd	Inu-ewe, Soka Area, Ibadan, Oyo-State	About 1000 ft^3	Functioning to full capacity
Bisrod Furniture Limited	Ijebu-Ode, Ogun-State	About 3000ft^3	currently running skeletal production
Stark Industries	Sango-Ota, Ogun-State	About 3600 ft^3	currently running skeletal production
Ladi otubu Wood Drying	Mushin, Lagos-State	About 1600 ft^3	currently running skeletal production
Nova Palcon Nigeria Limited	Plot 216, Trans Ekulu Layout, New GRA, Enugu, Enugu-State	About 1800ft^3	Currently inactive
TAC Factory	Owode Plank Market, Ondo Road, Ile-Ife, Osun-State	About 1000 ft^3	Functioning

Source: Authors' survey, from 2023 till date

2.2 Challenges Facing the Wood Drying Industry in Nigeria

The wood drying industry in Nigeria is constrained by a combination of economic, infrastructural, and environmental factors (Lucas & Olorunnisola, 2002). These challenges not only limit the growth of the sector but also adversely affect the quality and competitiveness of wood products in both local and international markets (Olorunnisola 2022).

2.2.1 Power Supply Constraints

Conventional kiln drying systems are designed majorly to depend on electricity (national grid) for their operations. Particularly, the air circulating fans are electricity-powered (Sejdiu, *et al*., 2015; Trujillo *et al*., 2021). However, the nation's (Nigeria's) inconsistent electricity supply severely impedes the efficiency and reliability of kiln operations (Ohagwu & Ugwuishiwu, 2011; Ashkin, 2013). Frequent power outages force operators to rely on diesel or petrol generators, increasing operational costs and reducing

economic viability. Moreover, fossil fuel combustion in these processes contributes significantly to greenhouse gas emissions, thereby raising environmental concerns and contributing to climate change (Raimi *et al*., 2020; Orru *et al*., 2022).

2.2.2 Pollution from fossil fuels

An alternative means of powering the conventional kiln fans is the use of fossil fuel-powered generators. Unfortunately, combustion of fossil fuels in power generating sets is a major culprit which constitutes menace to the environment (Akindele *et al*., 2022 and Orru *et al*., 2022). The byproducts of fossil fuel combustion are a combination of pollutants (carbon dioxide, carbon monoxide, unburned hydrocarbon, particulate matter, nitrogen oxides and sulfur dioxide) in the air-which are often detrimental to human existence (Raimi *et al*., 2021). The resultant effect of greenhouse gases is contribution to global warming and climate change-which are topical issues of global concern (Atkinson, 2024).

2.2.3 Rising Fuel Costs

Fluctuating prices of petroleum products further exacerbate the financial burden on wood drying operations. Between 2012 and 2025, the pump price of Premium Motor Spirit (PMS) increased from ₦97 to ₦825 per liter, while Automotive Gas Oil (diesel) rose from ₦115 to ₦1501.05 per liter (Eregha *et al*., 2015; National Bureau of Statistics-NBS, 2023; NBS, 2025; Esifiho (2025). As a result, the cost of drying timber has escalated dramatically. Current estimates suggest that drying a 1”×12”×12’ sawn timber board costs between ₦800 and ₦1,000, while a 2”×12”×12’ board ranges from ₦1,500 to ₦1,800. These costs ultimately inflate the market prices of finished wood products, potentially reducing consumer demand and competitiveness (Sejdiu *et al*., 2015; Egbewole & Rotowa, 2018).

2.2.4 Use of Inadequate Drying Techniques

Due to cost constraints and infrastructural limitations, many manufacturers continue to utilize outdated drying equipment or adopt informal methods such as end-racking boards in the sun (Plate 1). These practices often yield substandard wood products which may increase the susceptibility of wood products to warping, cracking, and delamination (Plates 2: A, B, C, D &E). Additionally, improper seasoning reduces timber’s durability and resistance to biological degradation, further limiting its usefulness in structural applications (Rani, 2014; Parajuli *et al*., 2018).

Plate 1: End-racking of boards in the sun
Source: Author's survey, 2023

Plate 2: Warped panel door (A); Delaminated Table desk (B); Warped door post (C); Warped table top (D) & Delaminated (glulam) table top (E).

2.2.5 Unwarranted Substitution of Solid (Round) timber with MDF

The high cost involved and complexity of timber drying have made some manufacturers to substitute solid wood with medium-density fibreboard (MDF) which are more readily available and does not require seasoning (Jakimovska *et al*., 2016). However, Langdon *et al*. (2021) submitted that, MDF lacks the mechanical strength and durability of solid timber, particularly in structural and load-bearing applications. It is unfortunate that the increase in the utilization of MDF in many parts of Nigeria has skyrocketed over the years; however, the use of MDF is not justifiable considering its low resistance to moisture, poor load resistance capacity and tendency for dimensional instability. The MDF exhibits lower strength properties and higher failures when compared with round timber; hence, it not suitable for certain interior or exterior application (Ahmed *et al.,* 2020).

3.0 Consequences of crises in the wood drying industry

3.1 Unsustainable utilization of harvested (unseasoned) timber:

It is no gainsaying that utilization of unseasoned timber is unfortunately an improper and unsustainable way of utilizing harvested timber. Unseasoned timber undergo unwarranted distortion or drying defects which might have been avoided suppose the timber was dried prior to its utilization (Misganu *et al*. 2021). Utilization of unseasoned timber results into limiting durability and service life of timber products

3.2 Pressure on existing forest reserves

It is unfortunate to note that most of the existing forest reserves in Nigeria are either threatened or endangered (Muhammed & Rabiu, 2022 Ekakitie & Enakireru, 2024). Worse still, some forest timber resources have been threatened to extinction due to overexploitation or indiscriminate logging which were engendered due to mismanagement of harvested logs. As a result of utilizing unseasoned harvested timber, they perform poorly or below expectation in service. Hence, the necessity to fetch lumber as replacement for the failed product(s) ultimately arises. This scenario results into mounting pressure on the residual forest resource (timber). It may pose severe challenge to ensuring utilization on sustained yield basis (Ekakitie and Enakireru, 2024).

3.3 Loss incurred as a result utilization of unseasoned round timber

It is no gain saying that utilisation of unseasoned timber is a strong potential for huge waste generation. The moment unseasoned timber is processed into desired end use (wood products), the tendency of incurring unwarranted loss or wastes is high. This is because such wood products become more susceptible to degradation through activities of biodeteriorating agents (insects, fungi) which render the item limited in

time and space (Abimaje and Baba, 2014). According to Lima *et al*. (2022), presence of high moisture in wood increases that risk of timber (biological material) to degradation. Consequently, degraded wood products become less useful as they lose their relevance in service. Eventually, such wood products may be disposed of or discarded for untimely replacement-sometimes they permanently create a vacuum.

3.4 Discouragement to stakeholder

In applications where unseasoned timber is used, customers or stakeholders tend to lose their confidence in products manufactured from round timber. Consequently, this results into discouragement and resentment. Ultimately, the phenomenon may dovetail to poor patronage which negatively affects the poor reputation of round wood in the wood products industry. Reports by Ashkin (2013) and Misganu *et al*. (2021) buttresses the fact that end users often lose their confidence in, become indifferent and express discouragement towards sawn wood utilization due to failures of wood products manufactured from unseasoned timber products.

3.5 Wrong impression or signal on utilization of round timber

It is unfortunate that certain species have been wrongly tagged unfit, perishable or nondurable by wood products manufacturers and end-users. This wrong position ensue as a result of the failure to season timber when the need arises. According to Adebawo *et al*. (2021), Misganu *et al*. (2021) timber becomes less prone to rot when the moisture has been dried to, or below the dry rot safety line (moisture content of 20%). However, the practice of utilizing wet timber (MC of 21% and above) increases the chances of losing the wood products to degradation by rot. In order to alley the wrong impression disposed by stakeholders in the timber industry, it is imperative to season the wood before processing or utilization. Proper timber drying is a precursor to its utilization (Ashkin, 2013; Dadzie *et al*., 2015).

3.6 Deficiencies/dangers of utilization MDF

According to Langdon *et al*. (2021) health challenge, poor water resistance and structural failures are among factors limiting the utilization of MDF in structural application and furniture production.

4. Solar Kiln Drying: A Sustainable Alternative for Nigeria's Timber Industry

Through solar kiln technology, several designs of solar kilns have been fabricated for timber drying. Reports by Amoo-Onidundu *et al*., (2016); Amoo-Onidundu *et al*., (2020) and Ferrari *et al.* (2024) revealed that solar kiln drying of timber is a viable option in the wood drying industry. The chamber (Plate 1) is a greenhouse solar kiln fabricated for timber drying experiments at the Forestry Research Institute of Nigeria.

Plate 1: Interior view of solar kiln at The Forestry Research Institute of Nigeria

4.1 Solar Energy as a Sustainable Timber Drying Solution

Solar energy represents one of the most promising renewable energy sources for industrial applications, including timber drying. It is abundant, inexhaustible, and environmentally sustainable (Pirasteh *et al*., 2014). Solar kiln drying utilizes solar radiation to reduce the moisture content of timber, eliminating the need for fossil fuels and mitigating associated greenhouse gas emissions (Bekkioui *et al*., 2011; Mekhilef *et al*., 2011).

Studies have demonstrated that solar kilns can match or exceed the performance of conventional kilns in terms of drying efficiency and quality. Haque and Langrish (2006), Ali *et al*. (2013), and Pedro *et al*. (2015) all reported favorable results in terms of drying uniformity, energy savings, and wood integrity using various solar kiln designs. These systems are especially advantageous in tropical climates where solar irradiance is consistently high throughout the year. Unlike conventional drying systems that rely on electricity or diesel generators, solar kilns operate independently of grid power. This independence makes them particularly viable in contexts like Nigeria, where electricity infrastructure is unreliable and operational costs are high. Furthermore, the use of solar technology aligns with global sustainability goals and reduces the environmental footprint of the timber industry (Bond & Espinoza, 2016).

4.2 Feasibility of Solar Kiln Drying Technology in Nigeria

Nigeria's geographic location along the equator provides it with substantial solar radiation, positioning the country favorably for solar energy exploitation (Adeola *et al*., 2017). Research suggests that, after hydroelectric power, solar energy is the most viable renewable energy source

in Nigeria, outperforming alternatives such as wind or geothermal energy in terms of accessibility and consistency (Newsom, 2013; Onyinge *et al*., 2015; Bergel *et al*., 2015).

Empirical evidence supports the efficacy of solar kiln technology for local timber species. For instance, Ugwu *et al*. (2015) recorded a final moisture content (FMC) of 12.9% with an average drying rate (DR) of 0.18% per day, while Amoo-Onidundu *et al*. (2023) reported a more impressive FMC of 10.40% at an average DR of 11.12% per day for *Gmelina arborea*. These values are within the safe moisture content range of 10–12% recommended for structural wood applications (EN 14298:2004; Eliasson, 2006), indicating that solar kilns can achieve industry-acceptable drying standards.

Moreover, solar kilns can be locally fabricated at a relatively low cost, offering an affordable solution to small- and medium-scale wood product manufacturers. This affordability could lead to increased production efficiency, reduced cost of final products, and greater competitiveness in the timber market. With adequate investment and policy support, solar drying could play a transformative role in revitalizing the Nigerian wood processing industry.

5. Conclusion

This review highlighted the critical role of wood drying in enhancing the performance, durability, and market value of timber products in Nigeria. Despite the country's rich timber resources, the wood drying industry remains underdeveloped due to inadequate infrastructure, high energy costs, unreliable electricity supply, and limited adoption of modern technologies. The widespread, indiscriminate use of MDF, often without regard to its suitability, undermines the role of solid wood in construction and reduces the reputation of timber products manufacture from round timber. These constraints have led to suboptimal practices such as sun drying and the use of unseasoned timber, which compromise product quality and tarnish the image of round timber in the wood based-and wood products industries.

Solar kiln drying technology offers a viable and sustainable alternative to conventional drying methods. Its reliance on abundant solar radiation makes it particularly well-suited to Nigeria's tropical climate, enabling cost-effective, off-grid timber seasoning. Empirical studies affirm the capability of solar kilns to achieve acceptable moisture content levels for construction-grade timber, with drying rates that meet industrial standards. Furthermore, solar kiln systems are environmentally friendly, reduce operational costs, and can be fabricated locally, making them accessible to small- and medium-scale enterprises.

6. Recommendations

To harness the full potential of solar drying technology and revitalize the Nigerian wood processing industry, a multi-stakeholder approach is essential—one that involves policymakers, researchers, industry practitioners, and investors. Based on the tune of this review, the following recommendations are proposed:

1. **Awareness and Capacity Building**.
   Increased awareness campaigns and training should be conducted to educate stakeholders—particularly small-scale producers—on the benefits of proper timber seasoning and the advantages of solar kiln technology.
2. **Adoption and Scale-Up of Solar Kiln Technology**.
   Wood processing enterprises should be encouraged to adopt solar drying systems. Government and private sector partnerships can facilitate the fabrication and dissemination of affordable, locally adapted solar kiln designs.
3. **Policy Support and Infrastructure Investment**.
   Government should formulate and implement policies that promote sustainable forestry practices and support investments in renewable energy technologies for timber processing.
4. **Improved Energy Infrastructure**.
   While solar kilns offer off-grid benefits, a more stable national power supply would also support broader improvements in the wood processing sector.
5. **Research and Development (R&D)**.
   Continued R&D is needed to optimize solar kiln designs for local timber species, improve drying efficiency, and assess long-term economic and environmental impacts.

The process of running away from a situation or an entity relating to crises in the wood drying industry is not the panacea; stakeholders need to address issues that will enhance utilization of well-seasoned round timber in order to improve productivity and enhance sustainable timber utilization. By enhance the sustainability, quality, and economic viability of its wood drying industry, thereby strengthening its timber value chain and contributing to national development goals.

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Evaluation of Wild Edible Tree Species Abundance and Diversity in Yorro Local Government Area of Taraba State, Nigeria

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Abstract

This study evaluated the abundance and diversity of some wild edible tree species in Yorro LGA of Taraba State, Nigeria. The objectives were to identify wild edible tree species and explore their frequency of occurrence and diversity. Data were obtained through field survey and laboratory analysis. A sample intensity of 40% was used to randomly select four districts in the study area. A total of 12 plots (each measuring 50×50 m) were laid (3 plots per district) for field survey. Data obtained were analyzed using quantitative indices (Species richness, Shannon Wiener diversity, Shannon's evenness and Simpson's diversity indices) and qualitative statistical tools (frequencies and percentages). Results showed that a total of 315 individual wild food trees in 22 species and 16 families were enumerated. The study found *Vitellaria paradoxa* and *Zizipus mauritiana* as the most abundant species. Significant degree of diversity (2.12 and 2.02) and variable evenness (0.69 and 0.76) were recorded for Pantisawa III, Nyaja II district, respectively, implying comparable levels of wild edible tree species. This calls for urgent need to implement sustainable management solutions for these species.

Keywords: Abundance, Edible Tree species, Yorro, Diversity, *Vetellaria paradoxa* and *Ziziphus mauritiana*.

INTRODUCTION

Yorro local government area (LGA) vegetation constitutes major in-situ responsibilities of wild edible tree species (WETS) germplasm. WETS have been a significant part of diets for various ecosystems over centuries, offering a diverse range of health benefits (Borelli *et al*., 2020) as well as socio-economic and ecological considerations. These tree species are used for food and fodder (Talukdar e*t al*., 2021). They play crucial roles in medicine, ecological balance, biodiversity conservation and cultural heritage (Tahir *et al*., 2023). Nigeria's diverse ecosystems support a wide range of tree species (AgroNigeria, 2023), including WETS. The country is endowed with a rich biodiversity with an estimated plant species of about 7,895 from 338 families and 2,215 genera (Ayodele and Yang, 2012; Wakawa *et al*., 2016). Several studies have been undertaken on the diversity of tree species, however, little or no attention has been directed to wild edible tree species. Unfortunately, these

species have faced different types of threats due to increasing pressure and damage induced by human activities that alter their abundance and diversity. Díaz, *et al.* (2019) and Soba *et al*. (2023) affirmed that these multiple threats have intensified.

Wild edible trees constitute an important part of household food baskets and form an integral part of traditional ethnic foods across the world (Bhat *et al*., 2020; Wang *et al*., 2020; Mishra *et al* 2021). Wild edible trees provide a vital source of nutrients, especially in regions with limited access to cultivated crops (Mishra *et al* 2021). These trees are a crucial safety net during food shortages and seasonal variations (Feyssa *et al* 2011). Wild edible tree species contribute essential vitamins, minerals, and fiber, enhancing dietary diversity and combating malnutrition (Anjum and Tripathy, 2013). The sustainable use of these species is vital for achieving many important developmental goals (Soba *et al*., 2023) including food security. Similarly, continuous forest inventory offers information on tree species abundance and diversity, this information may be useful in identifying WETS that can improve nutrition and increase dietary diversity, thereby, becoming an important strategy in tackling food insecurity. In most of the developing countries of the world, hunger is increasing due to population explosion and high food prices (Imran *et al*., 2007).

The effect of food shortage is spreading from developing countries to the developed ones and millions of the world's most vulnerable (the rural poor), are facing starvation as food shortage bites hard and prices of food crops move upward every day (Smith and Edward, 2008; Akesa *et al*., 2018). There is growing interest to investigate the abundance and diversity of the neglected wild edible tree species as food security becomes a pressing concern. Therefore, the objectives of these study were to identify wild edible tree species and evaluate their frequency of occurrence and diversity. The evaluation of wild edible tree species has added new knowledge to food science and tree species ecology, this will contribute to a better understanding of the potential of wild edible tree species as a valuable resource for food security and biodiversity conservation.

MATERIALS AND METHODS

The Study Area

Yorro Local Government Area (LGA) of Taraba State was created in 1991. The LGA is located between latitude 8^0 42' N and 9^0 12' N and longitude 11^0 20' E and 11^0 45' E. It occupies a total land area of about 1, 304 km^2 (Figure 1). Yorro LGA is bounded to the north by Lau LGA, to the northeast and southeast by Mayo Belwa (Adamawa State), to the east by Zing LGA, to the west by Jalingo LGA and to the south by Bali LGA (Oruonye and Ahmed, 2017). Yorro LGA is made up of eleven (11) districts (council wards) which include Bikassa I, Bikassa II, Nyaja I, Nyaja II, Pantisawa I, Pantisawa II, Pupule, Pupule II, Pupule III, Sumbu I and Sumbu II (Eduweb, 2022). Yorro LGA has two distinct seasons: the wet season and the dry season. The wet season typically lasts from April through October. The wettest months are August and September. November through March are the dry season months. December and January have the lowest relative humidity, falling to around 15%. The mean annual temperature is 290°C; the highest temperature is 350°C, and the lowest is 150°C. Rainfall averages 1541 mm annually (Serapta (2020; Atlas Weather, 2024; Manpower, 2024; Weather Crave, 2024).

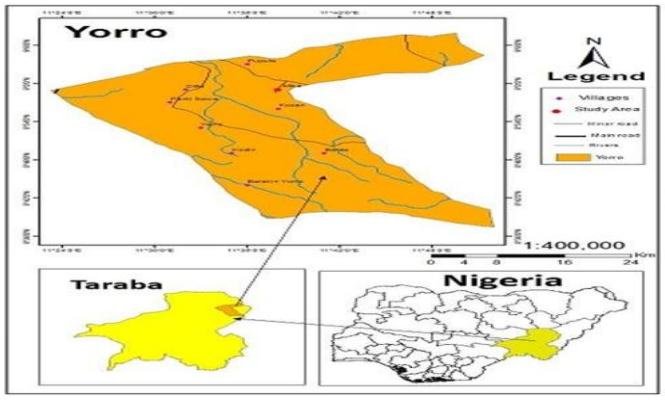

Fig. 1: Map of Nigeria showing Taraba state and the Study Area

Source: Oruonye and Ahmed (2017).

Yorro LGA is predominantly occupied by members of the Mumuye tribal division with other tribes like Fulani and Hausa (Manpower, 2024). According to National Population Census (2006), The population of Yorro LGA is put at 89,410 inhabitants (45,548 male and 43,862 female). Yorro LGA has a vibrant agricultural sector with the area known for the cultivation of a number of crops such as maize, millet, salads, onions, yam, maize, groundnut, guinea corn, bambara nut, millet, tiger nut, cassava and vegetables, as well as rearing of domestic animals like cattle, sheep and goats (Oruonye and Ahmed, 2017; Manpower, 2024). Trade also blossoms in the LGA with the area hosting a number of markets where a variety of commodities are bought and sold. Other important economic activities that take place in Yorro LGA include hunting and crafts making (Serapta (2020; Manpower, 2024).

The study area is a hilly and mountainous area, surrounded by chains of mountains, with only about 25 percent of the cultivated land (Oruonye and Abbas, 2011). The mountains here are part of the Shebshi Mountain which extends up to the Republic of Cameroon (Oruonye and Ahmed, 2017). The soil of the area consists of sandy loam soil which developed on the basement complex rocks in the region. Yorro LGA is drained by the Malale River and so many smaller streams that took their sources from the various mountains in the locality (Oruonye and Ahmed, 2017).

Data Collection

A sample intensity of 40% of the total number of districts (council wards), which include Bikassa I, Bikassa II, Nyaja I, Nyaja II, Pantisawa I, Pantisawa II, Pupule, Pupule II, Pupule III, Sumbu I, and Sumbu II, was used to randomly select four (4) districts for field survey. The randomly selected districts were Pantisawa II, Pupule III, Nyaja II and Sumbu I. A pilot inventory survey was first conducted to identify three distinct designated locations with a high population of wild edible tree species in each of the selected districts as adopted by Kayombo *et al*. (2020).

Three plots measuring 50 × 50 m were randomly laid in the designated locations, and a total of 12 plots were sampled in the study. All the individual wild edible trees occurring within the sampled plots were identified, counted and recorded in biodata sheets. The identification was done using colored plant identification guides developed by Keller (2004). In situations where identification was not feasible in the field, the common/local names of wild edible tree species were recorded, and specimens were collected for identification at the Herbarium of the Department of Forestry and Wildlife Management, Taraba State University, Jalingo, Nigeria. The experts at the herbarium assisted in identifying the specimens by comparing the newly collected voucher specimens with the existing herbarium specimens and consulting available published flora treatments and database records like Tropicos.org (2024).

Data Analysis

Data were analysis using both quantitative parameters and qualitative statistical tools as follows:

Quantitative Parameters

The quantitative parameters used in the study are diversity indices. According to Meer and Tella (2018), the species diversity index is the combination of the species richness (the number of species in the sample plots) and evenness of species (abundance distribution among species). Based on this, the diversity and evenness of the sampled wild food tree species were determined using the species richness (SR), Shannon-Wiener diversity index (H') and Shannon's evenness index (E).

The approach provided by Margalef (1951; 1968) and utilized by Japheth and Meer (2023), was employed to calculate species richness as follows:

Species Richness (SR) = $\frac{S}{\sqrt{N}}$ ……...…… ……...1

Where:

S = number of species in a collection

N = number of individuals collected

Following Saka *et al*. (2018), and Chenge *et al*. (2019), the Shannon-Weiner diversity index (H') was estimated using the equation 2.

Shannon-Wiener index (H') = -∑ (pi) lnpi …… …… 2

Where:

H'' = species diversity index.

P_i = the proportion of ith species in the sample

$\ln P_i$ = natural logarithm of species proportion.

Simpson's Diversity Index (SI) is a measure of diversity that takes into account both the number of species present and their relative abundance (Japheth and Meer, 2023). This parameter was determined using equation 3 below:

Simpson's Diversity Index (SI) = $\frac{1}{\sum_{i=1} R\ Pi^2}$ …… …… 3

Where:

pi = the proportional abundance for each species

R = the total number of species in the sample.

The Shannon's evenness index (E) was calculated following the formula adopted Meer and Tella (2018) (equation 3).

Shannon's Evenness Index (E) = $\frac{H'}{H_{MAX}}$ ……...…… …… 4

Where:

E= evenness index which has values between 0 (a situation in which the abundance of all species is completely disproportional) and 1 (all species are equally abundant).

H = Shannon Index

H_{MAX} = Natural logarithm of total number of Species.

Qualitative Statistical Tools

Descriptive statistics like frequencies and percentages were the qualitative statistical tools used.

RESULTS

Wild Edible Tree Species Occurrence in the Study Area

Table 1 presents the results of wild edible tree species occurrence in Yorro LGA of Taraba State. It revealed that 315 individual wild edible trees from 16 families were identified and recorded in the study area. Pantisawa II district had twelve species, representing eleven families; Pupule III district had 10 species from 7 families, and Nyaja II and Sumbi I district had 9 and 8 species,

representing 10 families each. Fabaceae, Malvaceae, Annonaceae, Arecaceae, and Rhamnaceae each had two species, whereas the remaining families had one each. Table 1 further explained that *Vitellaria paradoxa* had the highest frequency of occurrence (24.77%) in the study area, followed by *Zizipus mauritiana* (21.27%), *Adansonia digitata* (9.52%) and *Vitex donniana* (7.62%). *Vitellaria paradoxa* and *Adansonia digitata* were the most common wild edible tree species, with 28.99% and 7.46% in Pupule III and Pantisawa II districts, respectively. In Sumbi I and Nyaja II districts, *Vitellaria paradoxa* and *Zizipus mauritiana* were the most common species, with 46.74% and 32.18%, respectively. Due to their low frequencies, *Tamarindus indica*, *Parinari curatellifolia*, *Ficus sur*, and *Bombax costatum*, were identified to be the least wild edible tree species in Sumbi I, Pupule III, Pantisawa II and Nyaja II with frequencies of 1.09%, 1.45%, 1.49%, 3.45%, respectively (Table 1).

Table 1: Wild Edible Tree Species Occurrence Across the Districts in the Study Area

Species		**Family**	**District**									
Scientific Name	**Local Name**		**Pantisawa II**		**Pupule III**		**Nyaja II**		**Sumbu I**		**Total**	
			Freq.	**%**	**Freq.**	**%**	**Freq.**	**%**	**Freq.**	**%**	**Freq.**	**%**
Adansonia digitata	Bàmbúú	Malvaceae	5	7.46	9	13.04	5	5.75	11	11.96	30	9.52
Annona senegalensis	Gubduu	Annonaceae	-	-	2	2.89	5	5.75	-	-	7	2.22
Bombax costatum	Kuryaa	Bombacaceae	-	-	-	-	3	3.45	-	-	3	0.95
Borassus aethiopum	Giginya	Arecaceae	-	-	7	10.15	6	6.90	2	2.17	15	4.76
Ceiba pentandra	Rimi	Malvaceae	-	-	3	4.35	-	-	5	5.44	8	2.54
Detarium microcarpum	Taura	Fabaceae	3	4.47	1	1.45	-	-	-	-	4	1.27
Elaesis guneensis	Áláyyàdíí	Arecaceae	4	5.97	-		-	-	-	-	4	1.27
Ficus sur	Girca	Moraceae	1	1.49	-		-	-	2	2.17	3	0.95
Gardenia erubescens	Gaunde kura	Rubiaceae	2	2.99	-		-	-	-	-	2	0.64
Grewia mollis	Dargajii	Tiliaceae	2	2.99	-		-	-	-	-	2	0.64
Hexalobus monopetalus	Kelli	Annonaceae	-	-	5	7.25	-	-	-	-	5	1.59
Parinari curatellifolia	Gawasa	Chrysobalanacea	-	-	1	1.45	-	-	-	-	1	0.32

Parkia biglobosa	Dabano	Mimosoideae	-	-	-		8	9.19	7	7.61	15	4.76
Prosopis africana	Kirya	Mimosoideae	-	-	-		5	5.75	2	2.17	7	2.22
Spondias mombin	Saada	Anacardiaceae	14	20.89	-		-	-	-	-	14	4.44
Strychnos spinosa	Girgita	Loganiaceae	4	5.97	-	-	-	-	-	-	4	1.27
Tamarindus indica	Tsamiya	Fabaceae	2	2.99	8	11.59	-	-	1	1.09	11	3.49
Vitellaria paradoxa	Kadanyar	Sapotaceae	18	26.87	20	28.99	17	19.54	43	46.74	78	24.76
Vitex donniana	Dinyaa	Verbenaceae	-	-	-	-	4	4.59	-	-	24	7.62
Ximenia americana	Tsada	Olacaceae	2	2.99	-	-	-	-	-	-	2	0.64
Ziziphus spina	Kurna	Rhamnaceae	-	-	-	-	6	6.90	3	3.26	9	2.86
Zizipus mauritiana	Margaya	Rhamnaceae	10	14.92	13	18.84	28	32.18	16	17.39	67	21.27
Total	**22**	**16**	**67**	**100**	**69**	**100**	**87**	**100**	**92**	**100**	**315**	**100**

The Diversity of Wild Edible Tree Species in the Study Area

The results on Table 2 revealed that Pantisawa III district was the richest district (2.62) while Sumbi I was the least (1.09). Similarly, Pantisawa III district received the best Shannon Weiner index score of 2.12. followed by Nyaja II district (2.02). The lowest Shannon Weiner index (1.68), was noted for Sumbi I district. Pantisawa III district had the highest value (0.84), followed by Pupule II (0.83) while Sumbi I district had the lowest species Simpson's index (0.73). The district of Pantisawa III had an evenness index of 0.76, whilst the districts of Pupule II, Pantisawa III and Sumbi I had respective evenness indices of 0.72, 0.69, and 0.54 (Table 2).

Table 2: Wild Edible Tree Species Diversity in Yorro Local Government Area in Taraba State

Diversity indices	**Districts**			
	Pantisawa II	**Pupule III**	**Nyaja II**	**Sumbu I**
Richness (Margalef)	2.62	2.13	2.02	1.99
Shannon_H	2.12	1.97	2.02	1.68
Evenness_e^H/S	0.69	0.72	0.76	0.54
Simpson_1-D	0.84	0.83	0.83	0.73

DISCUSSION

The *Vitellaria paradoxa* and *Zizipus mauritiana* species had the highest percentage of occurrence. This implies that these species are the mostly abundance wild edible species in the study area. This claim is in line with a study carried out in a neighbouring Mayo Belwa LGA of Adamawa State, Nigeria, where Umar and Usman (2023), affirmed that *Vitellaria paradoxa* and *Zizipus mauritiana* were among the abundance species. Kwaga *et al*. (2016), Meer and Tella (2018), Meer *et al*. (2019) and in their findings also identified *Vitellaria paradoxa*, *Zizipus mauritiana*, *Adansonia digitata*, *Vitex donniana*, *Tamarindus indica*, *Parinari curatellifolia*, *Ficus sur*, and *Bombax costatum* as species occurring in northern part of Taraba State, Nigeria where Yorro LGA is located.

Species diversity assessment is a way of auditing an ecosystem to understand its dynamics and quality (Zimudzi and Chapano, 2016). The diversity values in the present study are closely related. This means that different districts within Yorro LGA have comparable levels of biodiversity, including species of wild edible trees. The richness and diversity indices of this finding suggest that Yorro LGA has a considerable degree of wild edible species diversity with variable distribution. This confirms with the previous study by Abba *et al*. (2022), who reported richness and Shannon diversity at 2.5 and 2.07, respectively. Though their evenness value of 0.55 is less than the evenness obtained in the present study. The diversity values recorded in this finding disagreed with the study by Olaniyi *et al*. (2023), who reported the highest Shannon diversity values of 4.54 and 0.703 for the highest and least plots, respectively. The government's strong measures to conserve the forests where these scholars did their findings might be connected to the higher diversity they reported. Bulenga *et al*. (2021), in their study of the Miombo woodlands ecosystem of Tanzania, reported a higher value (4.23) of the Shannon Wiener diversity index. Similarly, Zimudzi and Chapano (2016), Woldemariam *et al.* (2016), and Kalaba *et al.* (2013) reported higher values of 3.0, 2.97, and

2.8 Shannon Wiener diversity indices from Zimbabwe, Ethiopia, and Zambia, respectively. These differences could be connected to the fact the present finding focused on wild edible species.

CONCLUSION AND RECOMMENDATIONS

This study identified a total of 315 individual wild edible trees in 22 species and 16 families, with *Zizipus mauritiana* and *Vitellaria paradoxa* being the most abundance species. Pantisawa III district had the highest Shannon Weiner index (2.12) and evenness index of 0.76. This suggests that Yorro LGA has a considerable degree of wild edible tree species diversity with variable distribution. This finding has offered a useful reference evaluation of wild edible tree species by identifying species that are more economically and socially beneficial, thereby, enhancing their conservation opportunities. This calls for actions to improve the long-term sustainability and conservation of these species for the benefit of both human populations and the entire forest ecosystem. Increasing protection and environmental hazards prevention measures to increase the abundance and diversity of wild edible tree species in the study area should be a major priority.

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