JEBAT, 2025, Vol 8, No 2, 6-12
https://doi.org/10.54987/jebat.v8i2.1183

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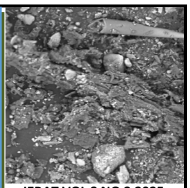

JEBAT VOL 8 NO 2 2025
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Diversity and Ecological Functions of Mycorrhizal Fungi in Nigeria: Current Status and Trend for Future Research

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History

Received: 10th Oct 2025
Received in revised form: 27th Nov 2025
Accepted: 30th Dec 2025

Keywords

Arbuscular Mycorrhizal Fungi
Ectomycorrhizal Fungi
Ecosystem Function
Nigeria
Biodiversity

SDG Keywords

SDG 2 Zero Hunger
SDG 13 Climate Action
SDG 15 Life on Land

Abstract

Mycorrhizal fungi are mutualistic symbionts of many terrestrial plants that improve soil structure, fertility, and ecological stability by helping plants absorb phosphorus, nitrogen, and minerals while providing carbon to the fungus. Studies on the variety of Arbuscular Mycorrhizal Fungi (AMF) and Ectomycorrhizal Fungi (ECM) in Nigeria are compiled in this review. It has been reported that *Glomus* species among AMF has dominant diversity and distribution across Nigeria, especially in the southwestern region while the northern region having underrepresentation of AMF studies, other genera like *Scutellospora, Gigaspora, Funneliformis, Septoglomus* and *Acaulospora* species were also reported. ECM studies remain limited and basically focused on mushroom surveys. Most investigations explore morphological identification methods for both AMF and ECM and focus more on mycorrhizal effects on growth and functions on food crops, neglecting their diversity and conservation concern. However, Root tip morphology assessment remains a knowledge gap for ECM studies in Nigeria. Molecular evaluation of species and diversity studies involving Operational Taxonomic Units (OTUs) are rarely applied, thereby limiting taxonomic and functional understanding. Future research should integrate molecular techniques, expand sampling across vegetation types, and establish national databases for long-term monitoring. Strengthening interdisciplinary collaboration and applying mycorrhizal knowledge to agriculture, reforestation, and soil restoration will promote biodiversity conservation, food security, climate change mitigation, and sustainable ecosystem management in Nigeria.

INTRODUCTION

Mycorrhiza is a mutualistic association established between fungi and a root of a plant, benefiting from one another in exchange of plant-derived photosynthate to soil nutrients and minerals [1]. Mycorrhiza are among the most well-known soil microorganisms, forming mutualistic associations with almost 90% of terrestrial plant species in the world. These relationships enhance plant access to essential less mobile nutrients such as phosphorus, nitrogen, and trace elements, while improving soil structure, moisture retention, and resilience to environmental stress [2,1]. This association does not only influence plant productivity and community structure but also play Significant roles in nutrient cycling, ecosystem functioning and carbon sequestration [3]. There are two major types of mycorrhizal fungi found in association with most terrestrial plant roots, namely, arbuscular mycorrhiza and ectomycorrhiza [1]. Glomeromycota were found widely spread for decades forming an association with more than 80% of plants roots [4]. AMF are endosymbionts forming arbuscles in the root cortical cells proving it with large surface area for nutrient exchange [5]. ECM fungi, on the other hand, form external sheaths called mantle around root tips of plants and mostly associates with trees in families such as Dipterocarpaceae, Fabaceae, Pinaceae, and Eucalyptus [6–8]. These organisms are key drivers in forest nutrient cycling and carbon dynamics, for their extensive mycelial networks linking below ground nutrients and the plant roots [9].

Global researches explored advanced molecular techniques, including next generation sequencing and meta-omics, proving detailed information for species identification and functional diversity [10,4]. Studies across different regions demonstrate climatic variables, soil pH, vegetation type, and land-use effect, strongly influence mycorrhizal community composition and diversity [11,12,7,13]. Despite this development in the field of knowledge, large regions in Africa, including Nigeria has limited

https://doi.org/10.54987/jebat.v8i2.1183

published papers in the literature compared to other continents [14]. Nigeria has different ecological zones, ranging from forest in the south to savanna in the north that harbor greater diversity of AMF and ECM, yet studies in their context remain limited and disjointed. Understanding their diversity and functions provide sustainable agricultural practice and ecological managements. Therefore, this review synthesizes existing literature on the diversity of Arbuscular and Ectomycorrhizal fungi in Nigeria and their roles in shaping ecosystem processes. We identify the status of mycorrhizal diversity and their role in ecosystem functioning, knowledge gaps and future research directions necessary for integrating mycorrhizal fungi into national biodiversity and soil management frameworks in Nigeria.

Diversity of Arbuscular Mycorrhizal Fungi (AMF) in Nigeria

Diversity of arbuscular mycorrhizal fungi (AMF) in Nigerian context have consistently revealed the dominance of *Glomus* species, particularly in the southwestern region, with notable variability in AMF composition across different plant hosts, soil types, and ecological zones. Dare et al. [15] examined the diversity of AMF in the rhizospheric soils of yam collected from four agroecological zones in Nigeria and identified thirty-one AMF species dominated by *Glomus* spp. Similarly, Abdurrahman and Rabiu [16] reported fifteen AMF species belonging to twelve genera from the rhizosphere of vegetable plants in the Kura agroecological zone of Kano State, Northwestern Nigeria, where *Acaulospora capsicula* and *Gigaspora margarita* were the most widely distributed species across vegetable rhizospheres.

In the southwest, Olubode et al. [17] found that all thirteen-upland rice (*Oryza sativa*) varieties examined were colonized by AMF, with spore densities ranging between 13 and 174 spores per 20 g dry soil (mean = 67.6). *Funneliformis mosseae* (formerly *Glomus mosseae*) occurred in 96.2 % of the samples, while *Glomus* remained the most dominant genus. Likewise, Adeyemi et al. [18] recorded *Glomus* spp. as the most dominant group in the rhizosphere of oil-seed crops collected from the derived savannah of the southwestern region. Seasonal variation effect has not yet been reported concerning AMF diversity in Nigeria.

Molecular surveys have further confirmed this dominance in forest ecosystems at Ise Forest Reserve from southwest, where 194 operational taxonomic units were identified belonging to six different families and 68% from Glomeraceae [19]. In the same trend, Thanni et al. [20] observed that *Glomus* species accounted for over 60 % of total AMF abundance in cassava (*Manihot esculenta*) rhizospheres within the same region, confirming the predominance of this genus in southwestern soils. AMF abundance was higher at uncultivated land than in the cultivated land type [21]. In contrast, studies conducted in the northern savanna regions indicate comparatively lower AMF studies, suggesting underrepresentation of AMF communities relative to the southern zones that is insufficient to draw into conclusion.

Despite the ecological importance of AMF in supporting plant productivity and soil health, most Nigerian studies have focused predominantly on food crops, with very limited investigations on trees, shrubs, and other perennial plant forms, which are equally significant components of terrestrial ecosystems. Hence, expanding AMF diversity studies to include phanerophytes and herbaceous species, most particularly within disturbed habitats and protected areas are critical research priority for understanding mycorrhizal ecology across Nigeria's diverse landscapes.

Diversity of Ectomycorrhizal Fungi (ECM) in Nigeria

Studies investigated on ECM diversity in Nigeria are lob-sided, reporting only mushroom diversity, although some mushrooms are ectomycorrhizal fungi and have a mutualistic association with plant roots. Buba et al. [22] reported 93 mushroom species across 29 families in a Nigerian savanna, noting that diversity peaked during the rainy season and highest under indigenous trees such as *Parkia biglobosa* and *Tamarindus indica*. Adeniyi et al. [23] recorded 151 mushroom species in a tropical forest reserve, with richness and diversity also greatest in the rainy season and strongly correlated with precipitation. Both studies revealed rich macrofungal communities across ecological zones, emphasizing habitat and seasonal influences on fungal diversity in Nigeria. There is paucity of information on the mushroom diversity in Nigeria to generate conclusion. However, there is very limited study published on ECM diversity in Nigeria, requiring urgent research intervention.

Ecological Roles of Mycorrhizal Fungi in Nigerian Ecosystems

Mycorrhizal fungi greatly influence nutrient cycling, stress tolerance in plants, bioremediation and carbon dynamics across Nigerian agroecosystems and disturbed landscapes. AMF increase water, phosphorus and other nutrient uptake in staple crops such as maize and cassava, improving growth and nutrient use efficiency under Nigerian field conditions [18]. Ibrahim et al. [24] and Ibrahim et al. [25] reported two rice varieties and soybeans mostly cultivated in northern Nigeria responded positively to different AMF inoculation in terms of growth and yield, indicating AMF as potential biofertilizer. Also, Olojugba and Kolawole [26] reported the positive impact of AMF in combination with NPK to the growth of cassava in Okitipupa and its environs of the southwestern region of the country.

AMF also improve plant water relations and drought tolerance in tropical crops buffering seasonal moisture stress common in Nigerian farming systems [27,26,28]. In polluted and degraded sites, such as oil-spilled, mining areas of and spent oil contaminated soil, mycorrhizal associations and AMF-assisted rhizoremediation and soil health promotion especially when combined with compost [29,30] Collectively, Nigerian studies and broader reviews show that integrating mycorrhizal management native AMF into restoration, sustainable agriculture and remediation strategies can increase crop resilience, improve soil health and accelerate recovery of degraded ecosystems.

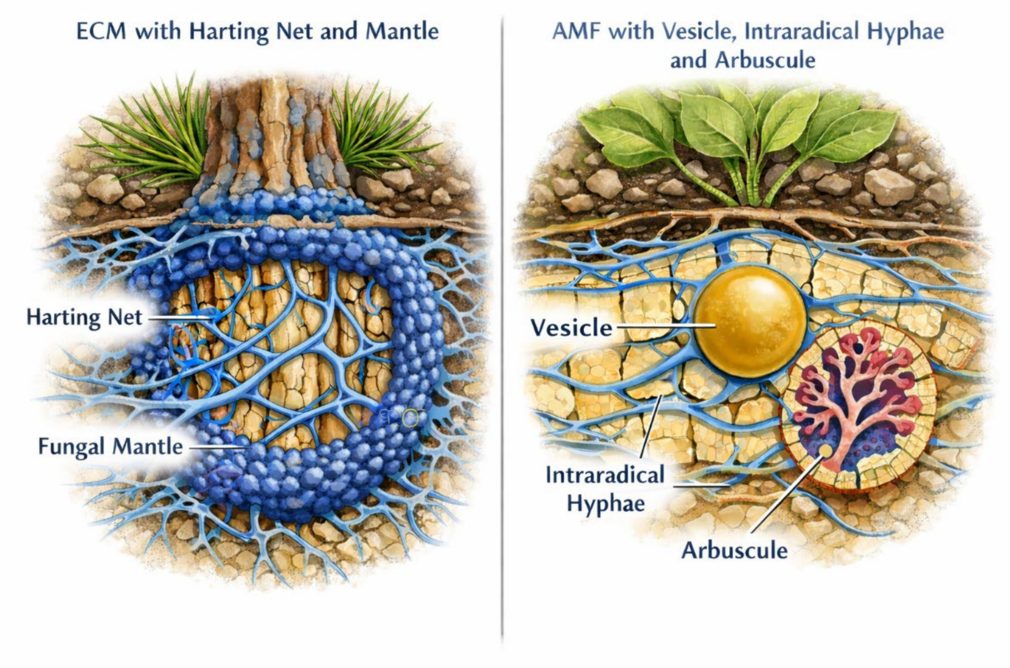

Fig. 1. Conceptual demonstration of mycorrhizal associations with plant roots. Left: ectomycorrhizal fungi (ECM) forming a mantle and Hartig net around root cortical cells. Right: arbuscular mycorrhizal fungi (AMF) from the phylum Glomeromycota forming intracellular arbuscules and vesicles within root cortex cells. Adapted from [1].

Methodological approach in Nigerian studies

Methods for AMF assessment in Nigerian research

Mycorrhizal researches in Nigeria, employed diverse field and laboratory techniques for determining mycorrhizal diversity, colonization levels, and ecological interactions. Sampling generally conducted in cropland, forest, and savanna ecosystems, focusing on rhizospheric soils and roots of dominant and economically important plant species [18,15,21,17,31]. The extraction and identification of arbuscular mycorrhizal spores in most Nigerian studies commonly employ the wet-sieving and decanting method of Gerdemann and Nicolson [32] and the sucrose centrifugation technique described by Daniels and Skipper [33]. These techniques were applied by Dare et al. [15] in yam rhizospheres across four agroecological zones, Abdurrahman and Rabiu [16] in vegetable rhizospheres from Kano, in addition, Abdurrahman and Rabiu [34] on native AMF diversity and relative abundance associated with cucumber in kano. The spores are typically identified morphologically based on spore size, color, wall structure, and hyphal attachment, as demonstrated by Adeyemi [18] and Egboka et al. [21].

Quantification of root colonization is generally achieved using the gridline-intersect method of Giovannetti and Mosse [35], which estimates the percentage of root length colonized by fungal structures such as arbuscules, vesicles, and hyphae. This technique has been adopted in Nigerian studies to determine colonization intensity and percentages in crop and tree roots [16,18,36,37,17,38].While most earlier studies relied solely on morphological identification, recent works have integrated molecular approaches such as Polymerase Chain Reaction (PCR) and sequencing of rDNA regions (ITS, SSU, or LSU) for more accurate species identification of AMF and other root-associated fungi in the rhizosphere of cultivated crops [39,19,20]. These studies demonstrate a gradual transition from classical morphological taxonomy to molecular-based characterization in Nigeria. Environmental parameters such as soil pH, organic carbon, nitrogen, phosphorus, and texture are usually measured and correlated with mycorrhizal distribution using multivariate analyses. This approach was employed by Yakasai and Rabiu [34] and Egboka et al. [21] who reported that soil chemical properties significantly influenced AMF community composition and abundance across different land-use types. Despite these advances, most Nigerian studies continue to rely on morphological identification, which limits taxonomic resolution. The adoption of metabarcoding and next generation sequencing is still limited, underscoring the need for future research to integrate molecular techniques for comprehensive assessment of AMF and ECM diversity across Nigeria’s vegetation zones.

Methods for ECM assessment in Nigerian research

Ectomycorrhizal research in Nigeria primarily relied on field observation of sporocarps (fruiting bodies) and microscopic characterization of spores and mycelial structures. Researchers such as Adeniyi et al. [23] and Buba et al. [22] collected mushroom and fungi fruiting bodies from forest soils in southern Nigeria and Northern savanna respectively, and identify them based on macromorphological features like pileus, stipe and lamellae and micromorphological characters, including spore shape, ornamentation, and spore print color. These studies followed standard mycological identification keys [40–42] and mushroom expert website. However, no single study found conducted in Nigeria that uses root tip assessment and molecular approach for ECM colonization and identification. In contrast to the Nigerian situation, current international practice in ECM ecology relies heavily on quantitative root colonization techniques and DNA-based tools to resolve cryptic diversity that cannot be distinguished reliably from fruit-body surveys alone.

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https://doi.org/10.54987/jebat.v8i2.1183

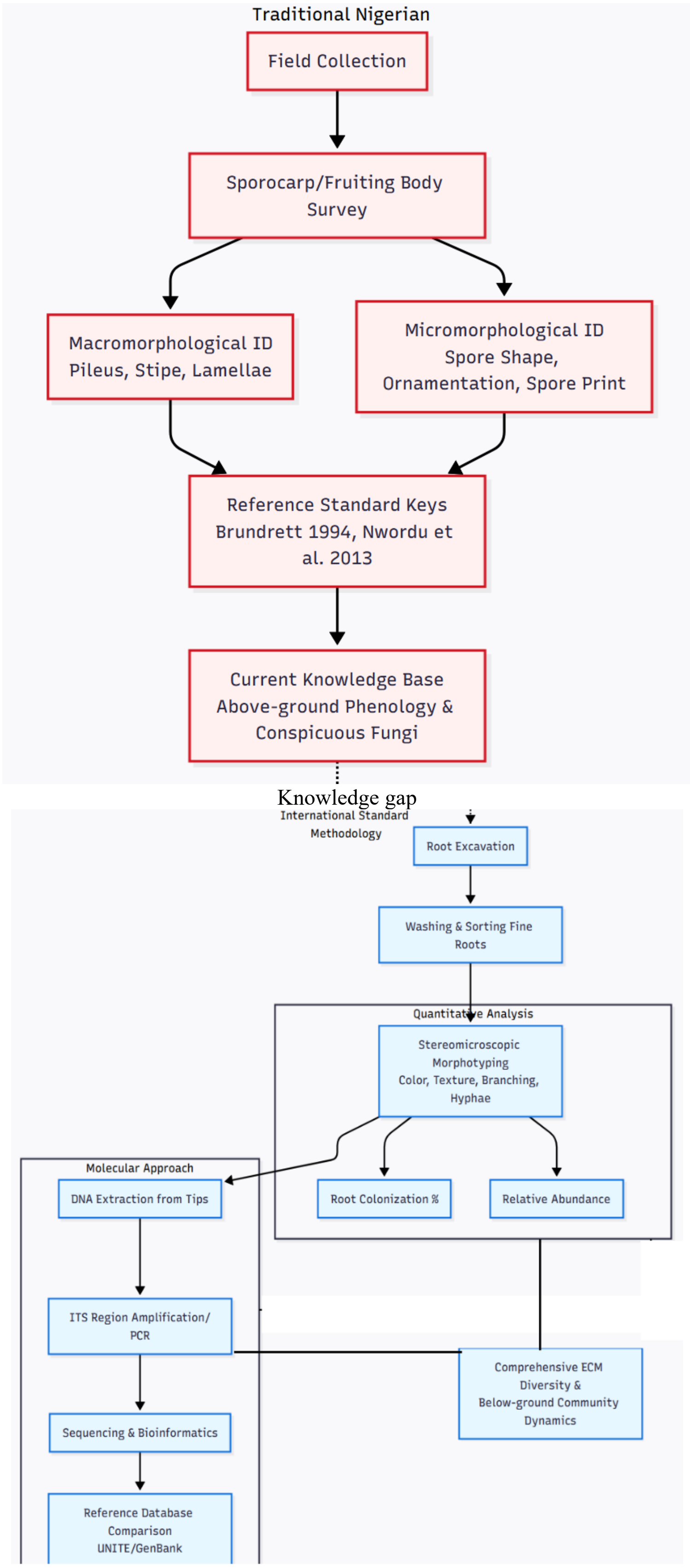

Fig. 2. Methodological gap in Nigerian ECM research. The flowchart contrasts existing fruiting-body-based identification (macro- and micromorphology) with modern integrated approaches utilizing root excavation, stereomicroscopic sorting, and DNA sequencing of the ITS region for comprehensive community analysis.

https://doi.org/10.54987/jebat.v8i2.1183

Typical root-based ECM assessment involves excavation of fine roots from known host tree species, careful washing, and stereomicroscopic sorting of ECM root tips into distinct morphotypes based on mantle color, surface texture, branching pattern, emanating hyphae and rhizomorphs. Each morphotype can then be quantified as a proportion of total root tips to estimate percentage ECM colonization and relative abundance of different ECM taxa on the root system. Brundrett's (1994) developed methods for staining and clearing of AMF roots. Furthermore, the method in combination with sectioning technique could be used for ECM root harting net visualization, and scoring. These methods can be adapted for ECM assessments in woody plants [43].

Beyond morphology, molecular approaches such as amplification and sequencing of the internal transcribed spacer (ITS) region from individual colonized root tips and sporocarps, followed by comparison with reference databases, are now considered the most reliable ECM identification procedure in environmental samples. ITS-based barcoding of the root tips overcomes the limitations of sporocarp-only surveys, which miss non-fruiting or inconspicuous species and can misrepresent below-ground community composition. Recent African ECM studies have combined root tip metabarcoding with species hypothesis (SH) matching to uncover diverse and often endemic ECM communities across Guineo-Congolian rainforests, Sudanian woodlands and Miombo systems, highlighting clades such as Russulaceae, Inocybaceae, Thelephoraceae and Sebacinaceae as dominant below-ground. These methodological advances underscore the gap in Nigerian ECM research, where similar vegetation types and ECM host genera occur but have not yet been investigated with root-based and molecular approaches [44].

Due to Nigeria's heavy reliance on fruit body surveys, most of the current knowledge is based on above-ground phenomena and the subset of fungi, such as Agaricaceae, Polyporaceae, and other common macrofungal families found in forest reserves and savanna landscapes, that frequently produce noticeable basidiomata. Although these inventories are essential, integrating them with assessments of root colonization would enable researchers to measure the degree of ECM infection, evaluate how land use, seasonality, and soil characteristics affect below-ground symbioses, and directly correlate sporocarp occurrence to host tree roots. A crucial methodological frontier for comprehending ECM function, variety, and conservation in Nigeria's forests and woodlands is the future adaptation of recognized techniques for ECM root morphotyping, clearing and staining, and ITS-based sequencing to Nigerian settings [45].

Research Priorities and Future Directions for Mycorrhizal Studies in Nigeria

Future studies on mycorrhizal fungi in Nigeria should cover native herbaceous species, trees, and shrubs in a wide range of environments, in addition to food crops. Accurate identification and comprehension of AMF and ECM diversity and functionality require the integration of molecular and high-throughput DNA sequencing approaches. Furthermore, studies should also integrate root tip colonization for ECM fungi, which is currently lacking in Nigeria, and connect fungal diversity to environmental factors including soil characteristics and carbon sequestration to mitigate climate change. To improve soil fertility, climate resilience, and biodiversity conservation, national mycorrhizal databases should be established, long-term ecological monitoring should be established, and mycorrhizal management should be integrated into programs for agriculture, reforestation, and ecosystem restoration.

Research across Nigeria's ecological zones must be collaborative and multidisciplinary in order to close existing knowledge gaps and bring the nation into compliance with global advances in mycorrhizal ecology. Adding methods such as metagenomic-based population studies can link mycorrhizal diversity and community structure with carbon sequestration and environmental variables such as soil texture, pH, moisture, and land management. Ultimately this will provide an evidence base for using mycorrhizal fungi as nature-based climate solutions. It is noted that recent reviews highlight that AMF and ECM can significantly influence soil carbon stabilization through hyphal networks, glomalin related soil proteins, and altered litter decomposition, but region-specific data from Africa are still sparse.

Nigeria could therefore prioritize manipulative field experiments and long-term observational plots that test how mycorrhizal inoculation, reduced tillage, organic amendments, and mixed species plantings affect both crop yields and soil carbon storage [46]. Additional priorities include to establish long term ecological monitoring and creating national mycorrhizal databases are. Successful lessons can be learned from initiatives such as the UK's Natural Capital and Ecosystem Assessment (NCEA) mycorrhiza programme and large-scale ectomycorrhizal monitoring frameworks, which integrate mycorrhizal data into national soil surveys and forest inventories.

It is important that a Nigerian mycorrhizal database be compiled based on georeferenced records of AMF and ECM taxa from roots, soils, and sporocarps, along with metadata on host species, habitat, soil chemistry, and climate variables. The link of these data with global repositories such as UNITE for fungal ITS barcodes and MaarjAM for AMF would ensure interoperability and enhance the visibility of Nigerian datasets [47]. Incorporate of mycorrhizal management into programs of agriculture, reforestation, and ecosystem restoration as methods to enhance soil fertility, climate resilience, and biodiversity conservation. It is also important to include locally adapted AMF and ECM inoculum, to tests using consortia in nursery and field trials, and also the development of mycorrhizal indicators in the criteria for successful restoration process for degraded forests, spent mined lands, and degraded coastal systems.

CONCLUSION

Mycorrhizal fungi are vital to nutrient cycling, plant productivity, and ecosystem stability in Nigeria. Existing studies reveal the dominance of *Glomus* species for Arbuscular Mycorrhizal Fungi (AMF) among others, while research on Ectomycorrhizal Fungi (ECM) remains scarce and limited to macrofungal identification. Most investigations rely on morphological methods as well as focused on food crops, with little attention to trees, shrubs, or native vegetation that support complex mycorrhizal networks. The lack of molecular and root-tip analyses restricts accurate species identification and ecological interpretation. Advancing mycorrhizal research in Nigeria requires integrating molecular and high throughput sequencing tools, expanding studies across vegetation zones, and establishing national databases for long-term ecological monitoring. Strengthening interdisciplinary collaborations will enhance understanding of mycorrhizal diversity and promote their application in sustainable agriculture, soil restoration, and climate resilience. Embracing these approaches will position Nigeria as a key contributor to global mycorrhizal ecology and biodiversity conservation.

ACKNOWLEDGEMENT

The authors declare that this research was self-funded. The authors also gratefully acknowledge the support and facilities provided by the author's institution throughout the course of this study.

AUTHOR CONTRIBUTIONS

Writing of the original draft; Lawal, A.S., Editing, Review and Supervision; AbdulHameed, A., Supervision; Nayaya, A.J., Supervision; Ezra, G.A.

CONFLICT OF INTEREST

Authors declare that they have no competing interests

DATA AVAILABILITY STATEMENT

Data available on request.

AI USAGE DECLARATION

The author used generative AI for language editing only. The author takes full responsibility for the content.

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