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Arbuscular mycorrhizal fungi and soil quality: a synthesis focused on West Africa

Champignons mycorhiziens arbusculaires et qualité des sols : une synthèse axée sur l'Afrique de l'Ouest

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Abstract

Arbuscular mycorrhizal fungi (AMF) are root symbionts that play a crucial role in soil health and the resilience of agroecosystems, particularly in West Africa, where soils are often degraded. This literature review analyzes the evolution of research on AMF, their mechanisms of action on soil structure and fertility (glomalin, biogeochemical cycles), as well as their potential for carbon sequestration. A bibliometric approach was used to select and analyze 887 relevant publications from international databases. It reveals a significant increase in publications on AMF over the past three decades, reflecting a growing interest in these organisms. The taxonomic diversity of AMF is influenced by multiple environmental and anthropogenic factors, with notable variations according to ecological zones and land management systems. AMF improve soil quality through several mechanisms: aggregate structuring via glomalin production, contribution to biogeochemical cycles, enhancement of plant resistance to stress, etc. This synthesis also highlights the still underexplored richness of AMF diversity in West Africa, particularly in Togo, and emphasizes their usefulness in strengthening sustainable agriculture in the face of climate challenges. Research perspectives are proposed to address the identified gaps and promote the use of these microorganisms in local agricultural practices.

Keywords: Arbuscular mycorrhizal fungi, soil quality, glomalin, carbon sequestration, agroecosystems, West Africa.

Résumé

Les champignons mycorhiziens arbusculaires (CMA) sont des symbiotes racinaires qui jouent un rôle crucial dans la santé des sols et la résilience des agroécosystèmes, en particulier en Afrique de l'Ouest où les sols sont souvent dégradés. Cette revue de littérature analyse l'évolution des recherches sur les CMA, leurs mécanismes d'action sur la structure et la fertilité des sols (glomaline, cycles biogéochimiques), ainsi que leur potentiel de séquestration du carbone. Une approche bibliométrique a été utilisée pour sélectionner et analyser 887 publications pertinentes issues de bases de données internationales. Les résultats révèlent une augmentation significative du nombre de publications sur les CMA au cours des trois dernières décennies, traduisant un intérêt croissant pour ces organismes. La diversité taxonomique des CMA est influencée par de multiples facteurs environnementaux et anthropiques, avec des variations notables selon les zones écologiques et les systèmes de gestion des terres. Les CMA améliorent la qualité des sols à travers plusieurs mécanismes : structuration des agrégats via la production de glomaline, contribution aux cycles biogéochimiques, amélioration de la résistance des plantes aux stress, entre autres. Cette synthèse met également en évidence la richesse encore insuffisamment explorée de la diversité des CMA en Afrique de l'Ouest, notamment au Togo, et souligne leur utilité pour le renforcement d'une agriculture durable face aux défis climatiques. Des perspectives de recherche sont proposées afin de combler les lacunes identifiées et de promouvoir l'intégration de ces microorganismes dans les pratiques agricoles locales.

Mots clés : Champignons mycorhiziens arbusculaires, qualité des sols, glomaline, séquestration du carbone, agroécosystèmes, Afrique de l'Ouest.

1. Introduction

Arbuscular mycorrhizal fungi (AMF) are widespread soil microorganisms that play an essential role in ecosystem functions (Ma et al., 2023). AMF, belonging to the phylum Glomeromycota, form symbiotic relationships with 80% of all vascular plants and are found in their roots (Smith & Read, 2008). Fossil records and molecular clock dating suggest that all existing terrestrial plants originated from an ancestral state of arbuscular mycorrhiza. These fungi co-evolved with the first colonization of land by plants around 450 to 500 million years ago and persist in most existing plant taxa (Cairney, 2000). Numerous studies have established the ecological and agronomic importance of AMF. With their network of hyphae, these microorganisms specialize in acquiring low-mobility soil nutrients, particularly phosphorus (Ferrol et al., 2019). They also contribute significantly to soil structuring, plant resistance to biotic and abiotic stresses, and biogeochemical cycles (van Der Heijden et al., 2015). AMF thus appear as key elements for the development of sustainable and resilient agriculture in the current context of climate change and soil degradation. Despite the recognized importance of AMF, many questions remain. The diversity, ecology, and role of these microorganisms in ecosystem functioning, particularly in tropical regions such as West Africa, are areas that still need to be explored. In Togo, as in many African countries, studies on AMF remain limited, although these microorganisms could play a significant role in improving the fertility of often-degraded soils and optimizing local agricultural systems. In this review, we rely on four main themes to synthesize current knowledge on AMF and their role in soil quality in West Africa. In particular, based on a synthesis of existing knowledge, we identify major gaps along these main axes and propose research perspectives to better understand and harness the potential of these microorganisms in the West African context, specifically in Togo.

The four main axes addressed by this review are the evolution of research on AMF, the influence of AMF on soil quality, the presence and potential of AMF in African agroecosystems, and the role of glomalin in carbon sequestration.

2. Materials and methods

2.1 Data collection

The bibliometric research was conducted using the software *Publish or Perish 8* (Harzing, 2007), which enabled queries across several bibliographic databases, including Scopus (https://www.scopus.com), Web of Science (https://www.webofscience.com) and Google Scholar (https://scholar.google.com). This approach allowed the combination of quantitative and qualitative criteria to select publications related to the main themes of the mini-review. Searches were carried out using keyword combinations in both French and English, employing the Boolean operators “AND” and “OR” to broaden or narrow results depending on the specific needs of each review axis. Keywords included: “arbuscular mycorrhizal fungi,” “soil quality,” “glomalin,” “agroeco-systems,” “carbon sequestration,” “West Africa,” “Togo,” “champignons mycorhiziens arbusculaires,” “qualité des sols,” “glomaline,” “Afrique de l’Ouest,” “agroécosystèmes,” and “séquestration du carbone.” Some examples of queries used are:

- ✓ “arbuscular mycorrhizal fungi” AND “soil quality” AND “West Africa” OR “Togo”
- ✓ “champignons mycorhiziens arbusculaires” AND “glomaline” AND “Afrique de l’Ouest”
- ✓ “glomalin” AND “soil aggregation.”
- ✓ “arbuscular mycorrhizal fungi” AND “Togo” OR “West Africa.”
- ✓ “Togo” AND “champignons mycorhiziens.”
- ✓ “arbuscular mycorrhizal fungi” AND “carbon sequestration” AND “agroecosystems” AND “Africa” OR “West Africa”

In addition to *Publish or Perish*, other databases were directly consulted, including Science Direct (https://www.sciencedirect.com), ResearchGate (https://www.researchgate.net/), and specialized databases such as the International Collection of Arbuscular Mycorrhizal Fungi (INVAM) and MaarjAM, an online database dedicated to AMF DNA sequences (Öpik et al., 2010). These complementary searches helped identify key and relevant publications related to the themes addressed

2.2. Inclusion and exclusion criteria

Several criteria were applied to narrow and guide the bibliometric research toward the study's objectives. These inclusion and exclusion criteria were used during the collection of scientific productions.

❖ Inclusion criteria applied were**:**

- Publications in peer-reviewed journals;
- Scientific articles, books, theses, reports, meta-analyses, and original studies;
- Publications mainly from the last 30 years (1995–2024), with the inclusion of older foundational works;
- Studies on AMF related to soil quality, agroecosystems, and glomalin;
- Studies conducted in Africa, particularly West Africa, or presenting results relevant to the African context.

❖ Exclusion criteria included:

- Non-peer-reviewed publications;
- Purely methodological studies without ecological or agronomic implications;
- Publications with incomplete data or insufficiently described methodologies;
- Studies focusing exclusively on other types of mycorrhizae.

This bibliometric analysis initially retrieved 2,065 publications, including scientific articles, thesis, dissertations, reports, books, conference abstracts, and posters related to the selected keywords. After database screening and duplicate removal, 887 publications were retained, reviewed, and categorized according to the three main themes of the study.

The most relevant publications were analyzed using a review matrix to extract the following information:

- Research objectives and questions;
- Methodologies used;
- Key findings and conclusions;
- Implications for understanding AMF in relation to the addressed themes;
- Limitations and future research perspectives.

3. Results and Discussion

3.1. Evolution of research on AMF related to soil quality

Temporal trends in publications and the geographical distribution of studies were analyzed based on data obtained from the bibliometric analysis.

3.1.1. Temporal trends in publications

The analysis of the 887 selected scientific publications provided insights into the evolution of research on AMF related to the studied themes (AMF and soil quality; AMF and agroecosystems; glomalin and carbon sequestration), with a particular focus on West Africa studies.

The bibliometric analysis reveals a significant increase in the number of publications on arbuscular mycorrhizal fungi over the past three decades (Figure 1). This trend reflects the growing interest of the scientific community in these microorganisms and their role in terrestrial ecosystem functioning. The annual number of publications on AMF related to the addressed themes increased tenfold between 2000 and 2024. The publication of the third edition of the reference book Mycorrhizal Symbiosis by Smith and Read and the rise of molecular approaches starting in 2010 marked a turning point in AMF research, contributing to the acceleration of publications, as shown in Figure 1. These techniques made it possible to explore the cryptic diversity of AMF and clarify their taxonomy, which had long been based solely on morphological characteristics.

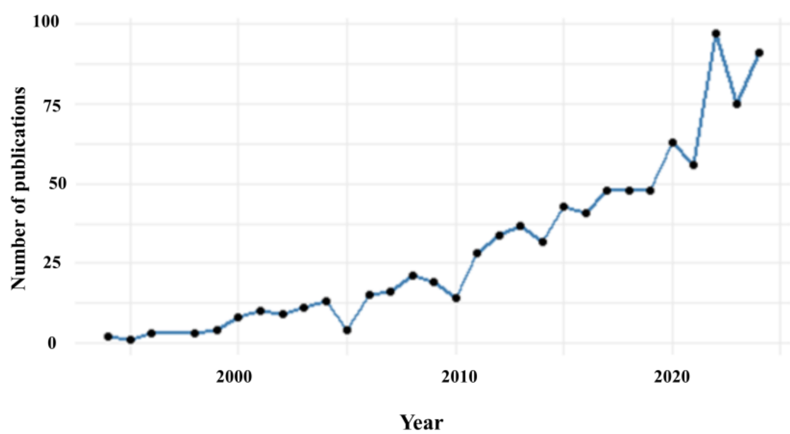

Figure 1: Evolution of research on AMF related to the studied themes (1995–2024)

3.1.2. Geographical distribution of studies

The geographical distribution of studies on AMF related to soil quality, agroecosystems, and glomalin in carbon sequestration shows a marked imbalance among regions of the world (Figure 2). Based on the 887 publications, most research was conducted in Asia (37.42%), Europe (11.95%), and North America (12.40%), despite the study's focus on the African continent. This is because publications relevant to the addressed themes primarily originate from Asia, Europe, and North America. These themes remain underdeveloped in Africa, despite the focus on the continent in the article selection criteria. South America (8.9%) also accounts for a low percentage, indicating that although tropical regions host a high diversity of AMF, they remain relatively underexplored, as confirmed by Davison et al. (2015).

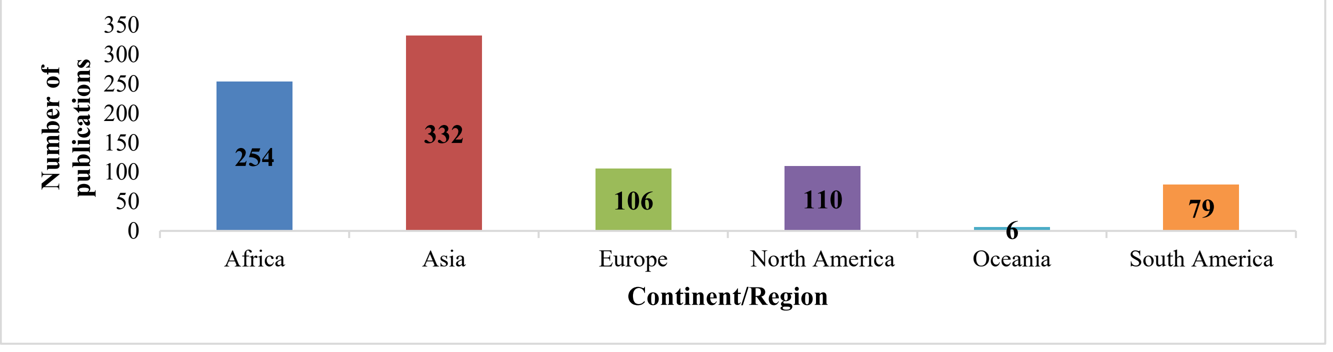

Figure 2: Geographical distribution of studies on AMF related to the addressed themes worldwide

In Africa, research on AMF related to soil quality, agroecosystems, and glomalin in carbon sequestration has increased over the past decade, but remains concentrated in a few countries, notably South Africa, Kenya, Morocco, and more recently, some West African countries such as Senegal and Nigeria (Figure 3). In Togo, research on AMF is still limited, although a few recent studies have begun to explore their diversity in certain agroecosystems (Alaba et al., 2021; Gnamkoulamba et al., 2018; Tchabi et al., 2009). The pioneering work of Tchabi et al. (2008) in Benin paved the way for new research in the region, demonstrating the influence of ecological parameters and land use practices on AMF communities

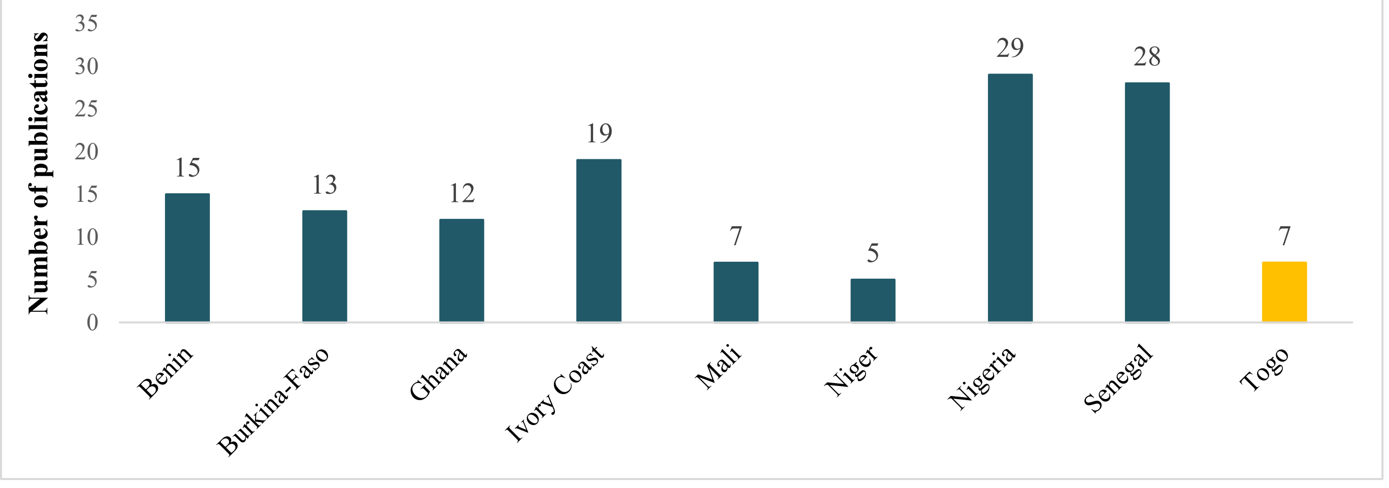

Figure 3: Geographical distribution of studies on AMF related to the addressed themes in West Africa

3.2. AMF and soil quality

3.2.1. Influence on soil structure

Rillig & Mummey (2006) identified three main mechanisms through which AMF contribute to soil structuring: physical entanglement of soil particles by the hyphal network, production of adhesive compounds such as glomalin, and interactions with various groups of soil organisms involved in aggregate formation. Figure 4 illustrates the role of arbuscular mycorrhizal fungi in the formation and stabilization of soil structure.

Figure 4 illustrates the symbiotic relationship between a generic host plant and arbuscular mycorrhizal fungi (AMF) in the soil, highlighting the carbon flow from the plant to the fungi and the phosphorus flow to the plant. Several studies demonstrate that in glomalin production and carbon sequestration, AMF play a major role as essential elements for soil aggregate stability and overall soil quality. Leifheit et al. (2014) showed that the overall mean effect of AMF inoculation on soil aggregation was positive, with predictive variables falling within the range of beneficial effects. They conducted the first study to quantitatively show that the effect of AMF inoculation on soil aggregation is positive and context-dependent. The authors concluded that their results could help enhance the use of this important ecosystem process as the application of inoculum in restoration sites. Glomalin, a hydrophobic glycoprotein produced by AMF, acts as a "biological glue" that binds mineral and organic particles together, forming stable aggregates resistant to erosion and degradation (Wright & Upadhyaya, 1996). Similarly, Rillig et al. (2001) demonstrated that AMF can also make significant direct contributions to soil organic matter through their influence on soil aggregation. Finally, Lehmann et al. (2017) proposed a conceptual model integrating the relative contributions of various soil organisms to aggregation, highlighting the synergies among AMF, bacteria, and soil fauna. These complex interactions demonstrate the need for a more holistic approach to understanding the role of AMF in soil structuring.

In the West African context, where soils are often subject to erosion and degradation (Lal, 1993), the role of AMF in stabilizing soil structure is particularly important. Daynes et al. (2013) developed a hierarchical soil aggregation model in which they highlighted the combined importance of organic matter (compost) and AMF inoculum in degraded soils, underlining their contribution to soil structure. These results show how AMF could be used as biological tools to combat soil degradation in West Africa, particularly in Togo.

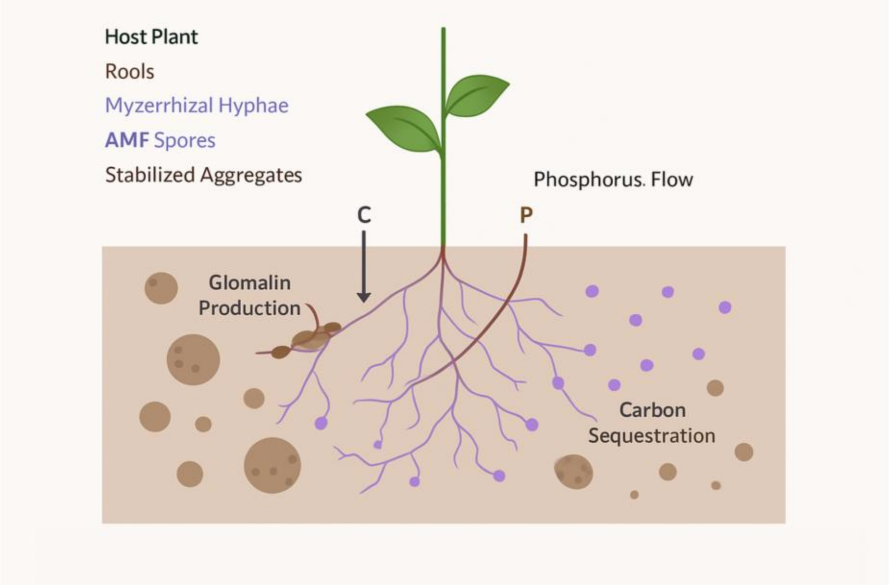

Figure 4: Role of arbuscular mycorrhizal fungi in soil quality

3.2.2. Contribution to biogeochemical cycles

Arbuscular mycorrhizal fungi play a crucial role in biogeochemical cycles, especially those of phosphorus, nitrogen, and carbon (Thiocone, 2024). Their contribution to these cycles directly affects soil fertility and ecosystem productivity, with the role of AMF in the phosphorus cycle being particularly well documented. Through their extraradical hyphal networks, AMF explore a much larger soil volume than roots alone, thereby accessing phosphorus pools unavailable to plants (Smith & Read, 2008). In addition, the secretion of phosphatase enzymes by AMF hyphal mycelia has been shown to significantly increase the utilization and mineralization of organic phosphate (Turner et al., 2007), demonstrating how AMF can mobilize poorly available phosphorus forms through enzyme secretion. Hodge & Storer (2015) emphasized that this ability of AMF to enhance phosphorus acquisition is especially important in tropical soils, where phosphorus is often limiting due to its strong fixation by iron and aluminum oxides. Regarding the nitrogen cycle, AMF contribute mainly to the acquisition of organic nitrogen and the reduction of losses through leaching. Bender et al. (2014) demonstrated that AMF can significantly reduce nitrous oxide (N_2O) emissions a potent greenhouse gas, by influencing microbial communities involved in denitrification. This finding highlights the potential of AMF to mitigate negative environmental impacts related to the nitrogen cycle in agroecosystems.

The role of AMF in the carbon cycle appears complex and is of increasing interest in the context of climate change. AMF represent a significant carbon sink, receiving up to 20% of carbon fixed through photosynthesis (Smith & Read, 2008). Part of this carbon is stored in fungal structures, particularly in glomalin, which has a relatively long residence time in the soil. Verbruggen et al. (2016) studied the role of AMF in stabilizing litter-derived carbon and concluded that these fungi can significantly contribute to soil carbon sequestration. However, Cheng et al. (2012) revealed a potentially contradictory effect of AMF on the carbon cycle: under certain conditions, particularly elevated CO_2, AMF can stimulate soil organic matter decomposition, resulting in CO_2 release. These results highlight the complexity of AMF carbon cycle interactions and the need to consider specific environmental conditions when assessing their impact.

In West Africa Sahelian region, where 95% of soils are sandy and nutrient-poor (McGahuey, 2021), the contribution of AMF to biogeochemical cycles is particularly important for soil fertility and agricultural productivity. Studies in Senegal by Diallo et al. (2006) showed that AMF can significantly improve nutrient use efficiency in Sahelian agricultural systems, offering potential for more sustainable agriculture in the region.

3.3.3. Soil quality indicators related to AMF

Soil quality, defined as its capacity to function as a living system to sustain biological productivity, maintain environmental quality, and promote the health of plants and animals (Doran & Parkin, 1994), can be assessed through various indicators. Arbuscular mycorrhizal fungi and related parameters are relevant biological indicators of soil quality. Cardoso et al. (2013) reviewed soil quality indicators and emphasized the importance of biological parameters, particularly those related to AMF, for a holistic evaluation of soil health. These indicators include the diversity and abundance of AMF spores, the root colonization rate, the length of extraradical mycelium, and the glomalin concentration in the soil.

The diversity and abundance of AMF spores reflect the soil's capacity to support these beneficial microorganisms and, by extension, to provide associated ecosystem services. Bowles et al. (2017) conducted a meta-analysis on the effects of tillage and cover crops on AMF and concluded that these parameters are sensitive indicators of land management practices. High AMF spore diversity and abundance are generally associated with high-quality soils that are minimally disturbed and rich in organic matter.

The mycorrhizal colonization rate of roots, which measures the extent of the symbiosis between plants and AMF, is another key indicator of soil quality. Soumare et al. (2015) studied the effect of Eucalyptus camaldulensis amendment on soil properties and

AMF activity in Senegal and observed a positive correlation between colonization rate and several soil fertility parameters, including organic matter content and enzymatic activity.

The glomalin concentration in soil, which is easily measurable using biochemical methods, is an integrative indicator of AMF activity and their contribution to soil quality. Rillig et al. (2003) showed that glomalin concentration is sensitive to land-use changes, decreasing significantly when forests are converted to agricultural land. This sensitivity makes it a relevant indicator for assessing the impact of management practices on soil quality.

These studies highlight the potential of AMF-related parameters as indicators of soil quality, especially in the West African context, where assessment methods must be adapted to local conditions and available resources. Integrating these indicators into soil monitoring and management programs could support more sustainable land use in Togo and across the region.

3.4. AMF in African agroecosystems

3.4.1. Synthesis of case studies in West Africa

Studies on arbuscular mycorrhizal fungi (AMF) in West African agroecosystems have increased over the past decade, revealing the diversity and potential of these microorganisms for regional agriculture. These studies cover various cropping systems and agroecological zones, offering an increasingly comprehensive view of AMF communities in the region.

In Benin, the pioneering work of Tchabi et al. (2008, 2009) laid the foundation for AMF research in West Africa. Their study on AMF communities in savannas and forests of Benin revealed significant diversity, with 60 spore morphotypes identified, and highlighted the influence of land use intensity and ecological zones on these communities. Their research on mycorrhizal symbiosis in yams, a major staple crop in West Africa, also demonstrated the promiscuous nature of this symbiosis and its potential to enhance yam production in the region.

In Ivory Coast, Amani et al. (2023) studied the diversity of AMF associated with cocoa trees and identified 15 species belonging to 5 genera, with Glomus and Acaulospora being the most prevalent. They observed significant variations in AMF diversity and abundance depending on plantation age and management practices, emphasizing the importance of these factors in maintaining AMF communities in cocoa-based agroforestry systems.

In Togo, studies on AMF remain limited, but some recent work has begun to explore their diversity and potential. Gnamkoulamba et al. (2018) investigated the prevalence and diversity of AMF spores in rice-growing systems across five agroecological zones in Togo and identified 25 species belonging to 7 genera. They observed that spore diversity and density varied significantly with cropping systems and agroecological zones, with the highest values recorded in lowland rice systems.

These case studies illustrate the diversity of AMF in West African agroecosystems and their potential to improve agricultural productivity and the sustainability of production systems. They also highlight the importance of considering local specificities, particularly pedoclimatic conditions and traditional agricultural practices, in the study and utilization of AMF in the region.

3.4.2. Impact of agricultural practices on AMF communities

Agricultural practices have a considerable influence on arbuscular mycorrhizal fungal communities in African agroecosystems. Several studies have analyzed these interactions, identifying practices that are either favorable or detrimental to the maintenance of diverse and functional AMF communities.

Agroforestry systems, which are widespread in West Africa, appear particularly conducive to AMF development. Bainard et al. (2011) reviewed AMF abundance and diversity in agroforestry systems and concluded that these systems generally harbor more diverse AMF communities than monocultures. The permanent presence of trees, plant diversity, and reduced soil disturbance in these systems creates favorable conditions for AMF.

In Senegal, Dieng et al. (2014) studied soil microbial communities, including AMF, in response to the planting of *Jatropha curcas* in the Sahelian zone. They found that introducing this plant into traditional farming systems significantly altered AMF community composition, with potential implications for soil functioning.

Soil management practices, such as tillage and fertilization, also influence AMF communities. Diop et al. (1994) studied indigenous AMF associated with *Acacia albida* in Senegal and observed that traditional parkland management characterized by minimal tillage and no chemical fertilization supported diverse AMF communities. In contrast, agricultural intensification, including deep plowing and the use of chemical inputs, generally leads to reduced AMF diversity and abundance.

Water management, especially important in drought-prone regions like the Sahel, also affects AMF communities. Diouf et al. (2005) studied the symbiosis between *Acacia auriculiformis*, *Acacia mangium*, AMF, and *Bradyrhizobium* under saline stress in Senegal. They demonstrated that dual inoculation with AMF and *Bradyrhizobium* significantly improved salt tolerance in these species, highlighting the potential of AMF to support adaptation to water and salinity stress in the region.

Agroecological practices such as agroforestry, conservation agriculture, and the use of organic amendments appear especially promising for promoting AMF abundance and diversity, offering opportunities for sustainable agriculture in West Africa, particularly in Togo. The ability of these microorganisms to enhance nutrient uptake, stress resistance, and soil structure makes them key elements in addressing the region's agricultural challenges.

In Senegal, Duponnois et al. (2001) investigated the mycorrhizal infectivity of soils and AMF spore communities in fallows of different ages. They found that restoring mycorrhizal infectivity in degraded soils through appropriate fallow periods significantly improved soil fertility and subsequent crop productivity. This approach, based on managing indigenous AMF communities rather than relying on inoculation, could be particularly suited to the conditions faced by smallholder farmers in Africa.

AMF also shows potential for adaptation to climate change, a major challenge for African agriculture. Diallo et al. (2006) studied the biological effects of indigenous and exotic plant residues on soil bacterial communities in a Sahelian region and observed that certain combinations of plant residues and AMF significantly improved soil resilience to water stress. This suggests that integrated management of plant residues and AMF could form a climate change adaptation strategy for farmers in the region.

Despite this potential, the use of AMF in West African agriculture remains limited due to several constraints, including a lack of knowledge about local AMF communities, difficulties in large-scale inoculum production, and the absence of appropriate regulatory frameworks. Further research will be needed to overcome these barriers and develop approaches tailored to the specific conditions of West African agroecosystems, particularly in Togo.

3.5. Glomalin and carbon sequestration

3.5.1. Production and stabilization mechanisms

Glomalin is a hydrophobic glycoprotein produced by the hyphae of arbuscular mycorrhizal fungi (AMF), discovered in the 1990s by Sara Wright and her collaborators (Wright & Upadhyaya, 1996). This protein, initially identified through its reaction with a monoclonal antibody developed against spores of *Rhizophagus intraradices*, has attracted growing interest due to its role in soil aggregate stabilization and carbon sequestration. Glomalin production by AMF is a complex process still only partially understood. Rillig et al. (2001) suggested that glomalin is mainly produced by the extraradical hyphae of AMF and released into the soil during their decomposition. The amount of glomalin produced varies considerably depending on the AMF species, environmental conditions, and host plants. Singh et al. (2013) reviewed the factors influencing glomalin production and emphasized the importance of interactions between AMF, host plants, and soil conditions in this process.

Once released into the soil, glomalin exhibits remarkable stability, with an estimated lifespan ranging from 10 to 50 years (Rillig et al., 2001). This stability is explained by several factors, including its complex molecular structure, hydrophobic nature, and strong association with soil mineral particles. Gillespie et al. (2011) analyzed the composition of glomalin and found that it contains not only proteins but also lipids and humic materials, which may contribute to its resistance to microbial degradation. The stabilization of glomalin in the soil involves several mechanisms, including adsorption to mineral surfaces, incorporation into soil aggregates, and formation of complexes with metals. These mechanisms protect glomalin from enzymatic degradation and contribute to its long-term accumulation in the soil. Wright & Upadhyaya (1998) demonstrated that glomalin can account for up to 5% of the total soil carbon in certain ecosystems, highlighting its importance in the global carbon cycle. In the West African context, where soils are often subjected to harsh environmental conditions (high temperatures, marked wetting-drying cycles), the stability of glomalin may be affected. However, few studies have specifically analyzed the mechanisms of glomalin production and stabilization in African soils, representing a significant gap in our current knowledge.

3.5.2. Factors influencing glomalin concentrations

Glomalin concentrations in soil are influenced by environmental and anthropogenic factors. According to Rillig et al., (2003), they have studied glomalin response to land use changes and have observed that concentrations were generally higher in natural ecosystems than in agricultural lands. This difference is mainly explained by the disturbance of AMF communities and the reduction of fungal biomass in intensive agricultural systems. Vegetation type and plant diversity also influence glomalin concentrations. Lovelock et al. (2004) studied glomalin stocks in tropical rainforest soils and observed significant variations depending on vegetation composition and structure. Ecosystems characterized by high plant diversity and a large presence of highly mycorrhizal species generally exhibited higher glomalin concentrations. Soil properties, notably pH, texture, and organic matter content, play a crucial role in glomalin production and stabilization. Cornejo et al. (2017) studied the contribution of AMF inoculation to the bioremediation of a copper-contaminated soil and observed that glomalin concentrations were influenced by the physicochemical properties of the soil, particularly nutrient availability and the presence of heavy metals. Land management practices, particularly those affecting AMF communities, directly influence glomalin concentrations. Treseder & Turner (2007) reviewed glomalin distribution across various ecosystems and concluded that practices promoting AMF development, such as conservation agriculture or agroforestry, generally lead to an increase in glomalin concentrations in the soil. In the West African context, and particularly in Togo, the specific factors influencing glomalin concentrations remain largely unexplored. The region's particular pedoclimatic conditions, characterized by high temperatures, variable rainfall, and often degraded soils, could significantly affect glomalin production and stabilization.

3.5.3. Implications for climate change mitigation

Glomalin, through its contribution to carbon sequestration in the soil, presents significant potential for climate change mitigation. Also, Zhu & Miller (2003) analyzed the carbon cycle mediated by AMF in soil-plant systems and emphasized the importance of glomalin as a stable carbon reservoir in the soil. They estimated that glomalin could account for up to 15% of the carbon sequestered in soils, making AMF key players in terrestrial carbon sequestration. Averill et al. (2014) proposed a mechanism by which mycorrhizal fungi, including AMF, promote soil carbon storage. According to their model, competition between mycorrhizal fungi and decomposers for nitrogen limits the decomposition of soil organic matter, leading to carbon accumulation. This mechanism could explain why ecosystems dominated by mycorrhizal plants generally store more carbon in the soil than those dominated by non-mycorrhizal plants. Verbruggen et al. (2013) studied the factors determining the success of AMF establishment in agricultural soils and emphasized the importance of appropriate management practices to maximize their contribution to carbon sequestration. They recommended approaches such as reduced tillage, diversification of crop rotations, and the use of organic amendments to promote the development of AMF communities and, consequently, glomalin production.

Leifheit et al. (2015) demonstrated that AMF can reduce the decomposition of woody litter while increasing soil aggregation, thereby creating a dual positive effect on carbon sequestration. This mechanism could be particularly important in agroforestry systems, where the presence of trees and AMF may favor long-term carbon storage in the soil.
In the West African context, where soils are often degraded and low in carbon, promoting AMF and glomalin production could be an effective strategy to enhance carbon sequestration while restoring soil fertility. Traditional agroforestry systems, widespread in West Africa, could play a key role in this approach, combining agricultural production with carbon sequestration. However, further research is needed to precisely quantify the contribution of AMF and glomalin to carbon sequestration in different African ecosystems, and to develop management practices that maximize this contribution while meeting the needs of local farmers. This integrated approach could contribute significantly to climate change mitigation while promoting sustainable agriculture in the region.

3.6. Knowledge gaps and research perspectives

Despite significant advances in understanding arbuscular mycorrhizal fungi (AMF) and their role in soil quality, several gaps remain, particularly in the West African and Togolese context.

- A limited documentation of AMF taxonomic and functional diversity in West Africa. Although some studies have explored AMF diversity in specific countries, large geographical areas and many ecosystems remain unstudied. In Togo specifically, knowledge on AMF diversity is fragmented and limited to a few studies conducted in specific agricultural systems. Systematic inventories covering the country's various ecological zones and topographic profiles are needed to establish a solid reference database.
- An insufficient understanding of the interactions between environmental factors, land management practices, and AMF communities. The specific pedoclimatic conditions of the region, which are characterized by high temperatures, variable rainfalland often degraded soils, may significantly influence AMF distribution and activity. Understanding these interactions is essential for developing management strategies adapted to local conditions.
- A limited knowledge of the role of AMF in agroecosystem resilience to climate change. In a context of increasing climatic variability, the ability of AMF to enhance plant resistance to water and heat stress could be particularly valuable for African farmers. Experimental studies simulating different climate scenarios are needed to assess the potential of AMF as tools for climate change adaptation.
- a lack of accurate quantification of AMF and glomalin contributions to soil carbon sequestration in African ecosystems. Direct measurements of glomalin stocks and their temporal dynamics across various ecosystems and management systems are necessary to evaluate the actual potential of AMF in climate change mitigation in the region.
- The need for practical methods to promote AMF in African agricultural systems. Commercial inoculation can be costly and not always suitable for local conditions, while managing native AMF communities requires an in-depth understanding of their ecology. Innovative approaches that combine scientific knowledge and traditional practices could offer practical solutions tailored to the realities of African farmers.

These gaps offer numerous research perspectives for scientists working on AMF in West Africa and in Togo. Interdisciplinary approaches integrating microbiology, ecology, agronomy, and social sciences will be essential to address these challenges and fully harness the potential of AMF for sustainable agriculture in the region.

Conclusion

This literature review has synthesized current knowledge on arbuscular mycorrhizal fungi and their role in soil quality, with a particular focus on the African and Togolese contexts. The bibliometric analysis revealed a significant increase in AMF-related publications over the past three decades, reflecting growing interest in these microorganisms and their potential for sustainable agriculture. AMF contribute significantly to soil quality through various mechanisms: they improve soil structure via hyphal entanglement and glomalin production, actively participate in biogeochemical cycles, particularly those of phosphorus, nitrogen, and carbon, and serve as relevant biological indicators of soil health. These contributions are especially important in African contexts, where soils are often degraded and nutrient-poor. Studies conducted in African agroecosystems have shown the potential of AMF to enhance agricultural productivity and sustainability. Agroecological practices such as agroforestry, conservation agriculture, and the use of organic amendments generally favor the development of AMF communities and the associated ecosystem benefits. Glomalin, a glycoprotein produced by AMF, plays a crucial role in soil aggregate stabilization and carbon sequestration.

Despite these advances, many knowledge gaps remain regarding AMF in West Africa and Togo. Further research is needed to document AMF diversity in the region, understand their interactions with environmental factors and management practices, assess their potential for climate adaptation, quantify their contribution to carbon sequestration, and develop practical methods to promote their presence in farming systems.

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Conflict of interest statement

The authors declare that they have no conflict of interest in relation to this publication.

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