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Symbiosis to Sustainability: Exploring the Role of *Termitomyces clypeatus* in Ecosystem Services and Community Livelihoods in West African Forests

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ABSTRACT

Termitomyces clypeatus, a member of the genus Termitomyces, enjoys a strong symbiotic relationship with termites. This symbiosis between the wild edible mushrooms and termites yields innumerable provisioning, regulating, supporting, and cultural services through its contributions to the well-being of the members of the communities living along the forests in regions in which *Termitomyces clypeatus* thrive. West Africa is one of these regions. Their association with significant ecosystem services in ways that improve the livelihoods of communities establishes *Termitomyces clypeatus* as important members of the terrestrial ecosystem. This review evaluates existing literature and studies on the specific roles played by *Termitomyces clypeatus* in improving the well-being and livelihoods of communities in West African forests. The findings uncover relatively understudied links between *Termitomyces clypeatus*, termites, and the food insecurity and protein deficiency problems facing West African communities. The missing links establish the need for further investment in research on *Termitomyces clypeatus* to ensure that their potential as sources of food and medicine, ecological benefits, and roles in the maintenance of soil quality are realized fully.

Keywords: *Termitomyces clypeatus,* West Africa, food, medicine, soil quality.

INTRODUCTION

In 2021, a survey conducted to evaluate public opinion and knowledge of microorganisms uncovered a pervasive lack of knowledge about them among the public and widespread misconceptions regarding their role, importance, and usefulness (Spernjack, Puhmeister & Sorgo, 2021). Despite the limited universal knowledge of

microorganisms, some communities have traditionally harnessed their benefits, using specific microorganisms as sources of food and medicine for human beings and animals and agents of nutrient cycling in their ecosystems. West African communities, for instance, have had extensive ethnological knowledge of the uses of microorganisms as food and medicine, with some members of the communities commercializing this knowledge into sources of income and the basis of small businesses (Osarenkhoe, John & Theophilus, 2014). This knowledge has been developed for centuries through experimentation, advancing folk medicine practices in the region. One of the microorganisms that is widely used across West African communities is wild fungi. Various species of mushrooms are consumed all over the region, with Termitomyces, a symbiotic fungus, being the most common. The fungus gets its name from its symbiotic relationship with termites. It relies on the organic matter produced by termites after feeding from trees. The termites, in turn, degrades plant-based material such as wood, allowing termites to build their homes easily (Ghorai *et al.*, 2011).

Figure 1: *Termitomyces clypeatus (*Sharp & Minter, 2022*)*.

Termitomyces clypeatus (see figure 1) is a fungus that is common in Africa, particularly in West African countries such as Nigeria and Cameroon. The edible mushroom is sought across the region as a source of food for its high protein content without the harmful effects of common animal proteins due to its low-fat content and lack of cholesterol (Paloi *et al.,* 2023; Ghorai *et al.,* 2011). In addition to its nutritional benefits, *Termitomyces clypeatus* has a wide range of medical applications owing to its antibacterial and anti-tumor properties, high concentration of folic acid, vitamin C, and thiamin, and potential as an antioxidant (Sharma *et al.,* 2022; Ngoc, Khang & Dung, 2022). The crucial role played by the fungus in maintaining ecological balance completes its trifecta of benefits. Its symbiotic relationship with termites, which is crucial for the establishment of habitat for the termites in exchange for organic matter for sustenance facilitates the natural valorization of trees and other dead plant matter while maintaining the termite population to play its roles in the ecosystem. These roles include the maintenance of the physical and structural properties of the soil, the rehabilitation of polluted soils, and the creation of beneficial biostructures in their ecosystem (Jouquet *et al.,* 2011).

Evidently, the symbiotic relationship between *Termitomyces clypeatus* is well established, and elements of its significance and implications for the ecosystem have been identified. To determine the extent to which this knowledge and its applications in West African communities that have historically recognized and harnessed the benefits of the fungus are documented in literature. We review the role of *Termitomyces clypeatus* in its ecosystem, including its contributions to natural capital and how its dietary, nutritional, medicinal, and ecological applications have affected the livelihoods of the communities living around West African forests.

METHODS

This study uses literature on the symbiotic relationship between *Termitomyces clypeatus* and termites and the uses of *Termitomyces clypeatus* to determine how extensively the role of the wild mushrooms in ecosystem services and the livelihoods of communities living along West African forests has been studied and identify the provisioning, regulating, supporting, and cultural services they provide. The researcher used Google Scholar, Elsevier, SpringerLink, and Jstor to identify relevant information on the topic of study. To reflect both current and indigenous knowledge the year of publication was not part of the criteria. All identified relevant studies were screened rigorously to guarantee relevance and quality and the selected studies were synthesized to yield the results below.

RESULTS

The relationship between termites, edible mushrooms, including *Termitomyces clypeatus*, and the ecosystem has been well established in literature. A wide pool of literature focuses on the genus Termitomyces. The Royal Society of Chemistry identifies the genus as a type of wild mushroom that is fed on by termites and has a significant symbiotic relationship with different types of the insect that live both underground and above ground (Sharma *et al.*, 2023). Various studies describe the foundation of the symbiotic relationship between the two species as one that provides shelter for the termites and food for the Termitomyces. Essentially, termites create a conducive and protective environment for Termitomyces to grow and thrive in their colonies in addition to providing plant biomass, which serves as a source of food for the edible mushrooms. The Termitomyces, on the other hand, degrade plant substrates, allowing termites to build their homes easily. In addition to their foundational role in the establishment of the colonies' habitat, the mushrooms provide food to the termites, which, in turn, aid in the

dispersal of spores, ensuring the continued reproduction and growth of Termitomyces (Paloi *et al.*, 2023). Since Termitomyces are fungi that produce asexually while termite colonies have life spans spanning decades, the mutualism between the fungus and termites enhances ecosystem stability (Wisselink, Aanen & Padje, 2020). Notably, the link between an undisturbed Termitomyces-termite mutualism and ecosystem stability, particularly if the termite colonies are left undisturbed and mushroom harvesting is either non-existent, minimal, or controlled, has not been explored.

Termitomyces clypeatus as a Source of Food

One of the primary contributions of *Termitomyces clypeatus* to ecosystem services lies in their nature as a source of food. The nutritional, dietary, and both current and potential contributions to food security are documented both generally and with specific emphasis on some West African communities. In its exploration of the phytochemistry and nutritional constitution of wild and edible mushrooms, the *Royal Society of Chemistry* identifies two ways through which *Termitomyces clypeatus* serves as a source of food (Sharma *et al.*, 2023). First, the Termitomyces species is a source of food for termites as one of its contributions to the symbiotic relationship between the two species (Paloi *et al.*, 2023). While the role of *Termitomyces clypeatus* and other mushrooms of the species as a source of food for termites is well-explored and documented but its link to the termite population they sustain as a source of food for human beings and animals is not explored. Nevertheless, the role of termites as a source of human and animal food has been studied, establishing a foundation for the missing albeit indirect link between *Termitomyces clypeatus* and termites as a source of food. For instance, in their exploration of termites as a source of food and medicine, Figueiredo et al. (2015) identify various termite species that are used in the human diet or the production of livestock feeds. The study registers 29 African countries that use termites as part of their diet and

to enrich animal feeds, including West African countries such as Nigeria, Senegal, and Guinea. Beyond serving as food for human consumption, a second indirect link between *Termitomyces clypeatus* is not established in literature but is easily inferred by linking together studies on the topic. Members of the genus Termitomyces are responsible for maintaining the termite population, which provides food for animals such as chicken and livestock, contributing to life-sustaining benefits such as the availability of milk, eggs, meat, and manure to boost agricultural production. However, since studies and literature on termites as a source of food fail to link the consumption of the insects to *Termitomyces clypeatus* and other edible mushrooms that feed the insects and enable them to build shelter, these indirect roles of the wild mushroom species to ecosystem services such as improving the nutrition and overall well-being of the West African communities that rely on termites as a source of food are not widely recognized.

Comparatively, the direct contribution of *Termitomyces clypeatus* and other members of genus Termitomyces to nutrition and community diets through their role as sources of food for human beings and animals is discussed widely together with its potential implications for food security across West Africa and other parts of the world. Termitomyces have been used extensively as a source of human food for ages (Sharma *et al.,* 2023). Paloi et al. (2023) identify the Yoruba people, a community indigenous to Nigeria, as one of the communities that have traditionally utilized members of the genus Termitomyces as a source of food as well as the production of nutritional supplements (Paloi *et al.,* 2023). A few countries away, in Côte d'Ivoire, various members of the genus Termitomyces, including *Termitomyces clypeatus*, have been mapped and their distribution, fructification, and uses documented in a study evaluating the diversity, phenology, and distribution of the fungus in the West African country (Kone *et al.,* 2018). One of the key focuses of the study was the socio-economic uses of Termitomyces in the country, which identified the role of the mushrooms as a source of food as crucial to both

the social and economic organizations of the country's communities. Notably, the study recognized the role of *Termitomyces clypeatus* and 8 other members of the genus Termitomyces as a source of food for termites and its role in the symbiotic relationship between the two species. Second, the study identified the role of Termitomyces as a source of food for various communities in Côte d'Ivoire, identifying the expansive savannah-forest boundaries that span across the Eastern and Western parts of the country as abundant sources of the wild mushrooms. The study acknowledges the crucial role played by *Termitomyces clypeatus* and the other members of the genus in the country's food security, particularly since the fruiting bodies of the fungus appear during the rainy season when the communities' food stocks are falling low and other crops are in various growing stages but not at maturity (Kone *et al.,* 2018). The communities' reliance on the wild mushrooms for sustenance during the rainy season is not unique to West Africa as it has been recorded in India as well, where local communities forage the mushrooms for domestic consumption and sale at their local markers during the rainy season (Kumari *et al.,* 2022).

The use of *Termitomyces clypeatus* as a source of food in many West African communities, other African communities, and in other parts of the world, is justified by their nutritional value, which is well documented in both studies that focus on the region under review and research studies that either focus on other regions or explore the fungus as a source of food in general. A study focusing on *Termitomyces clypeatus* as a direct source of food through the consumption of the flesh of the mushroom identifies physical properties and nutrient content that facilitate its consumption (Paloi *et al.,* 2023). These include the texture and flavor of the mushroom alongside its high protein and fiber content. Additionally, the mushrooms are good sources of vitamins, including ascorbic acid, thiamin, and riboflavin, contain essential minerals including potassium, selenium, iron, and phosphor, and have very low levels of fats and cholesterol. Evidence of the

scientific knowledge of their nutritive value and use of food among West African communities dates to past centuries (Ogundana & Fagade, 1982). Such knowledge has been enriched through the years and gained scientific legitimacy as more researchers explore and document the potential use of the symbiotic relationship between termites and the genus Termitomyces to address food insecurity. However, much of this research is not specific to West Africa, instead focusing on other countries or regions. One study focuses on tribes and communities in Eastern India, pointing out that traditional edible resources such as mushrooms, which have multiple nutritional benefits, could be the key to food security (Mndal, Saha & Saha, 2023). Since the highlighted communities share the cultural acceptance of mushrooms from the genus Termitomyces as a source of food with West African communities, the findings of the study could have similar implications on the potential of the wild mushrooms as the key to attaining food security in West Africa.

Just as the potential use of *Termitomyces clypeatus* and other members of the genus Termitomyces to address food security in West Africa is not highlighted explicitly in literature, the above missing link between the symbiotic relationship between *Termitomyces clypeatus* and termites and the role of termites as human and animal food extends to the implication of the symbiosis between the two species on food security. *Termitomyces clypeatus,* through their role in the growth of the termite population, could indirectly provide a solution to the current food crisis in Africa through the production of termites for food. The potential for the use of termites to promote food security has been studied and its viability established although the processes responsible for the growth of the population of termites, such as their symbiotic relationship with Termitomyces, have not been studied and documented as extensively. For instance, a study evaluating the potential contribution of edible insects to better nutrition and food security in Africa identified termites, whose consumption has a cultural rooting across the continent, as

one of the insects with the potential to feed the region (Kipkoech *et al.,* 2023). However, their consumption would require the deliberate farming of termites, which are currently harvested from wild ecosystems such as forests. The viability of termites as a solution to food security in Africa is supported by studies that describe the insects as a good source of proteins, vitamins, fats, and several essential nutrients and speculate that their cultivation would benefit poor households that struggle to access affordable and nutritious food (Netshifhefhe, Kunjeku & Duncan, 2018).

The Medicinal Value of *Termitomyces clypeatus*

Beyond the direct and indirect roles of *Termitomyces clypeatus* as sources of food for termites and human beings, the wild mushrooms have been established in scientific studies and literature on ethnomedicine as sources of medicine. Paloi et al. (2023) identify a few ethno-medicinal uses of Termitomyces among communities in Africa and Asia. While *Termitomyces clypeatus* is not identified as one of the members of the genus Termitomyces used specifically in West Africa, its ethnomedicinal uses in other parts of Africa and beyond the continent are identified and documented. In Ethiopia, for instance, the fungus is used as an intervention for underweight children and to treat gastritis and constipation in adults while in India and Nepal, the fungus is used to treat pox and yellow fever, respectively (Paloi *et al.,* 2023). Scientifically, according to the study, *Termitomyces clypeatus* has antioxidant properties that allow the fungus to protect the cells from damage by free radicals when consumed. The antioxidant properties of *Termitomyces clypeatus* are reiterated across several studies, which add antibacterial, anti-inflammatory, and cancer-fighting properties to the list of its medicinal properties (Tharavecharak *et al.,* 2023; Ngoc *et al.,* 2022). One study particularly details the use of *Termitomyces clypeatus* alongside three other species of wild mushrooms found in Nigeria as sources of antimicrobial and antioxidant extracts due to their high

concentration of bioactive compounds (Sitati *et al.,* 2021). The majority of the studies on the use of wild mushrooms of the genus Termitomyces focus on their traditional use with only a few scientific studies evaluating the claims that the species has medicinal value or determining the potential for their use in the pharmaceutical industry or the viability of their mass production for the purpose. One of the few scientific studies on the topic reinforces traditional knowledge of some medicinal qualities of *Termitomyces clypeatus* as held by West African communities through its findings that extracts drawn from the fungus inhibit the growth of bacteria and yeast, reverse immunosuppression caused by dexamethasone, and restore antibody formation (Mahamat *et al.,* 2018). Further, when tested on mice, the extract was found to reduce the lethality of *Pasteurella multocida*. These findings not only validate the traditional and cultural use of *Termitomyces clypeatus* as medicine but also introduce other potential medicinal uses of the fungus.

The above medicinal, nutritional, and dietary applications of *Termitomyces clypeatus* present an opportunity for improving the lives of communities living along or near the West African forests in which the wild mushrooms are found through trade. Studies detailing the foraging and sale of the wild mushrooms in local markets as a source of livelihood have been published. However, only a few of the mentions of such commercial trade in the mushrooms relate to West Africa. From the available literature, members of the genus Termitomyces, including *Termitomyces clypeatus,* are foraged and sold in local markets across Asia, particularly in Nepal, Thailand, China, and Sri Lanka (Paloi *et al.,* 2023). In Africa, commercial trade in the wild mushrooms under discussion has only been reported in Malawi, Zambia, and Rwanda (Paloi *et al.,* 2023; Morris, 1986), amidst reports that wild edible fungi, such as *Termitomyces clypeatus*, are underutilized and their potential underrecognized across the continent (Sileshi, Tibuhwa & Mlambo, 2023).

The Role of *Termitomyces clypeatus* in Overall Ecosystem Health

The contributions of *Termitomyces clypeatus* to ecosystem services as explored in research and documented in literature focus primarily on direct provisioning services, particularly the provision of food and medicinal resources. However, other indirect services, in addition to their role in the growth of the termite population and maintenance of termite colonies over their lifetime as discussed above, other roles of the wild mushrooms in the ecosystem that improve the overall well-being and quality of life of human beings have been studied. One notable topic of study is the role of *Termitomyces clypeatus* and their symbiotic relationship with termites in the maintenance of overall ecosystem health. The crucial role played by wild mushrooms in the maintenance of forests in the terrestrial ecosystem is acknowledged. In Ethiopia, for instance, the presence, growth, and overall status of mushrooms such as the members of the genus *Termitomyces clypeatus* are used as a source of information in forest management (Kewessa, Dejene & Martin-Pinto, 2023). This information, which is sought as part of an initiative to integrate wild mushroom production into the country's forest management practices resulted in an interesting outcome by becoming an incentive for the sustainable management of forest resources. Whilst, there are no studies linking *Termitomyces clypeatus* to a similar outcome in West Africa, some universal roles of the fungus have been reported, which could be attributed to any communities that use it for food, forest management, or as a source of medicine. One such role, which is linked to the overall well-being of the environment and the human population, is the optimum utilization of forest resources. *Termitomyces clypeatus* relies on dead plants and trees, facilitating their degradation (Das *et al.,* 2023). Such utilization of forest resources creates a cycle of benefits such as sustaining the termite population, which, in turn, enhances soil fertility and structure, enabling the continued growth of trees and vegetation in forests and nearby agricultural lands (Enagbonma & Babalola, 2019). While indirect and

not directly linked to West Africa in literature, the benefits of thriving forests and balanced soils improve the well-being of communities across the region.

DISCUSSION

The role of *Termitomyces clypeatus* in ecosystem services such as the provision of food and other resources, the regulation of soil quality, the provision of medicine for disease prevention and control, and the provision of a source of income for local communities living close to forests where the edible mushrooms thrive have been explored and documented in recent and past literature. According to most studies, Western African countries are some of the regions in which *Termitomyces clypeatus* and other members of the genus Termitomyces are indigenous. In countries such as Côte d'Ivoire, for instance, local communities, particularly communities that live close to the forest-savannah stretches in which wild mushrooms thrive, hold and pass down indigenous knowledge on the mushrooms and their uses (Kone *et al.,* 2018). Similar knowledge has been recorded in West African countries such as Nigeria, Senegal, and Guinea (Figueiredo *et al.,* 2015). The primary contribution of *Termitomyces clypeatus* in these communities is provisioning services, particularly in their role as good sources of protein, vitamins, and essential minerals. Studies have insightfully linked this role to food security since the wild mushrooms thrive during the rainy season when plant-based sources of food are scant as plants are in different stages of their growth. Studies further note that *Termitomyces clypeatus* is a good source of protein, an observation that is particularly significant since West Africa has one of the lowest rates of consumption of protein per capita compared to other parts of the world (Vissamsetti *et al.,* 2024). By providing an abundant source of food in a season when plant-based food, which makes up the largest proportion of the typical West African diet, is scarce, *Termitomyces clypaetus* provides a potential solution to the food insecurity and nutrition crises that have been reported

across the region (Vissamsetti *et al.*, 2024 & Kota, Chomienne & Yaya, 2023). However, from the available literature, the potential of *Termitomyces clypeatus* as a solution to food insecurity has only been explored theoretically with little input from local communities or physical efforts to establish projects targeting the subsistence or commercial production of wild mushrooms. Similarly, the exploration of the medicinal value of *Termitomyces clypeatus* has focused solely on exploring existing indigenous knowledge held by various local communities, including communities indigenous to West African countries, with some researchers confirming the medicinal qualities of the wild mushrooms using scientific methods. However, links to the pharmaceutical industry or the potential for the scaling of the production of the mushrooms for the mass production of antioxidants, vitamins and essential minerals, anti-inflammatory medication, or antibacterial medication are yet to be explored. Naturally, the potential commercial viability of the mainstream use of *Termitomyces clypeatus* in the production of medicine remains a largely unexplored element regardless of its economic implications on West African communities while the commercial potential of wild mushrooms in local trade in food among West African communities has been equally neglected regardless of its implications on the livelihoods of the communities. Finally, the crucial link between the indirect contributions of the symbiotic relationship between termites and *Termitomyces clypeatus* to ecosystem services such as food, trees and vegetation, agricultural productivity, and animal feeds remains unexplored in both current and past literature. While the contributions of termites as a source of food and the contributions of *Termitomyces clypeatus* to soil fertility, the valorization of dead plant and tree matter, and the maintenance of termite colonies have been studied, little research and resources have been dedicated to the recognition of their outcomes as some of the ecosystem services provided by the wild mushrooms and nor have they been studied with specific references to West African communities indigenous to the region's forested areas.

Ultimately, *Termitomyces clypeatus,* their symbiotic relationship with termites, their contribution to biodiversity and the well-being of human beings, and their potential to reduce food insecurity in West Africa, address nutrition deficiencies in the region, and contribute to pharmaceutical breakthroughs are largely underexplored. Future research efforts, resources, and funding should be dedicated to uncovering the innumerable benefits of the edible mushrooms.

CONCLUSION

Concisely, the symbiotic relationship between *Termitomyces clypeatus* and termites is not only beneficial to both species but also presents some ecosystem services that improve the lives of the communities that live along West African forests. Both *Termitomyces clypeatus* and termites, which rely on each other for sustenance, are a source of food for the communities, particularly during the rainy seasons when the plants that make up their predominantly plant-based diet are growing. Second, *Termitomyces clypeatus* plays a significant ecological role that facilitates the optimum utilization of forest resources and fertilizes the soil to support the growth of more vegetation, trees, and food crops. Third, the wild mushrooms have medicinal properties that have been harnessed by West African communities for generations. Together, the two species have the potential to offer more provisioning, regulating, and supporting services, warranting a call for more funding to scale their known benefits and increased research to uncover more benefits.

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