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The ecology of edible mushrooms of the Nigerian savannah: towards their optimal exploitation

Toma Buba[1], Veronica Agbo[2]; Aliyu Abdullahi[3].
[1] Department of Ecology, Faculty Science, Abubakar Tafawa Balewa University, Bauchi.
[2] Department of Microbiology Abubakar, Tafawa Balewa University, Bauchi. E-mail: vera14810@yahoo.com
[3] Department of Biological Science, Abubakar Tafawa Balewa University Bauchi. E-mail: aliyumicro@gmail.com
Corresponding Author: E-mail: tomabuba@gmail.com

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ABSTRACT
Objective: The objectives of this study was to identify the various microhabitats in which edible mushrooms grow; to identify their fruiting pattern time; and to relate the findings to their optimal exploitation in a Nigerian savannah.
Methodology and Results: The mushrooms were collected at the onset to the end of the rainy season. Mushrooms at different stages of growth were handpicked; photographed at different resolutions and their microhabitats and the month in which they were found was recorded. Species identification was archived by carefully examining the attributes of the sporocarps such as colour, shape, size, texture of the cap; and presence or absence of gills, etc. T-Test and Diversity Indices were conducted on the data. Thirty-one (31) different edible mushroom species were found in the study area. They largely belong to the families of Agaricaceae, Lyophyllaceae and Polyporaceae. They are found in 18 different microhabitats, which include Arable Lands; Fallow lands; soils around dead Tree Stumps; Woods; and 14 different living tree species. The highest species richness (15) and species diversity (Shannon Diversity index, SDI: 2.54) was found under *Parkia biglobosa* tree. The second was *Tamarindus indica*, having 8 species with 1.95 SDI; followed by Decaying Wood where 6 different mushroom species were recorded with SDI of 1.57. Collectively, the exotic trees habited 8 mushroom species, while the indigenous trees habited 18, which was significantly (p-value = 0.0001) different. Decaying Wood has the highest peculiar species, which was 5; Fallow have 4 species; followed by *Parkia biglobosa* that has 3 species. Out of the total 31 species 21 were found in the year 2016 and 24 in 2017, while only13 species were found in both 2016 and 2017, but the difference was not statistically significant (p-value = 0.961).
Conclusion and Application of results: The study area is rich in diverse edible mushroom species, which comprises mostly of those species belonging to the family Agaricaceae, Lyophyllaceae and Polyporaceae. The microhabitats of these mushrooms include arable lands currently under cultivation; abandoned fallow lands; soils around dead tree stumps; decaying woods; and 14 different living tree species. The result of this study has important information that can be an indispensable guide for proper exploitation of edible mushrooms in this region and elsewhere.
Keywords: Arable; Bauchi; Edible; Fallow; Microhabitat; Mushroom; Parkia biglobosa; Savannah Wood

INTRODUCTION

A mushroom is a fruiting body of macro-fungus that is produced above ground or substrate and is large enough to be seen with the naked eye and to be picked up by a bare hand (Royce, 1997; Wani *et al.,* 2010; Kumar, 2015). Many species of wild mushrooms are widely consumed as a delicacy in different part of the world. The consumption and other utilization of the wild mushrooms are increasing because of their high nutritional, organoleptic and pharmacological values. Apart from valued aroma and flavour, mushrooms are nutritionally desirable due to their low energy value, fibre content and high antioxidant capacity (Kalac, 2009). The taste, size and abundance of their fruiting bodies are very important factors to consider when selecting mushrooms as potential source food (Dı´ez and Alvarez, 2001). Several factors determine the nutritional and chemical constituents of mushrooms, which include species, geographical location, growth substrate, growth stage at harvest and part of the mushroom. Although information on the chemical composition of many edible mushrooms has been expanded dynamically during the last decade, the data can hardly be generalized because of large number of consumed species and great variability in chemical composition within individual even of the same species (Kalac, 2009; Sudheep and Sridhar, 2014). Generally, mushrooms contain vitamins, dietary fibre, proteins, minerals and all the nine essential amino acids required by human. Some edible mushrooms also contain bioactive compounds such as ascorbic, alkaloids, carotenoids, flavonoids, folates, glycosides, lectins, phenolics, terpenoids, tocopherols etc. These have implications for prevent or treat various types of disease (Kalac, 2013 Kumar, 2015; Valverde *et al.,* 2015). They are used for prevention or treatment of diseases such as Parkinson, Alzheimer, hypertension and high risk of stroke, tumour and cancer beside others. Other mushrooms act as antimicrobial agents; enhancer of immune system and an agents cholesterol lowering; (Valverde et al., 2015). Because of their nutritional and medicinal values; high productivity per unit area; and low input requirement in production, mushrooms are regarded as an excellent source of nutrition to alleviate malnutrition in developing countries and improve their economy (Pathmashini *et al.,* 2008). Edible mushrooms production is a very good opportunities for developing countries because it can ensure the sustainability of living and create job opportunities in rural communities. The rural communities have abundance by-products or co-products from other crops, which are the raw material for potential mushroom production. When properly exploited, production of mushroom could thus provide an alternative opportunity for additional source of income for small family enterprises (Celik and Peker, 2009). However, some mushrooms are poisonous or have some toxic properties. Some of the poisonous mushrooms are neurotoxic, causing hallucinations, anxiety, bronchospasm, confusion, nausea, and altered sense of time and space. Other toxic mushrooms cause gastrointestinal poisoning. Their symptoms include abdominal pain, diarrhoea, nausea, vomiting and even death (Fiedziukiewicz, 2013). Some edible mushrooms are also ectomycorrhizal fungi. The ectomycorrhizas are rhizosphere fungi that are capable of forming mutualistic associations with the roots of appropriate mycotropic plants (Rossi *et al.* 2007). The ectomycorrhizas provide a direct physical link between the nutrients and water in the soil matrix and the plant roots. This brings about increased root's hydraulic conductance by increasing the amount of contact with surfaces of the soil particles. The plants usually benefits form mycorrhizas through more efficient water and nutrient uptake, thereby increase its resistance to drought stress and optimized performance. The fungus in the other hand gets its supply of photosynthates from the plant (Jha and Kumar, 2011; Klavina, 2015; Torres-Aquino *et al.* 2017). Thus, suitable ectomycorrhizas can offer cheaper and efficient strategy to increase agricultural productivity on impoverished soils amid climatic change (Hrynkiewicz and Baum, 2011). These provoke the increasing interest of both researchers and consumers in mushroom hunting and cultivation (Kalac, 2009). In spite of this great economic importance, scientifically synthesized information on the ecology of many edible mushrooms globally, and particularly in Nigerian savannah, is too scanty to guarantee their optimum exploitation (Svenning *et* *al.,* 2018). These necessitate the need for this study.The general aim of this study was to survey the diversity of edible mushrooms in a Nigerian savannah. Specifically, 1) to identify the various microhabitats in which they grow; 2) to identify their fruiting pattern time 3); and to relate the findings to their optimal exploitation.

METHODOLOGY

The Study Area: The Study was conducted in a suburb of Bauchi city, located at longitude 10.263954º N and latitude 9.811298º E in North-East of Nigeria (Figure 1). The climate is characterized by alternating wet and dry seasons. The highest atmospheric temperature is recorded in the months of April and May and minimum temperatures occur in the months of December and January. The rainfall is about 600 to 900 mm per year, mostly between May and September (Yusuf and Yusuf 2008; Concha *et al.,* 2013). The end of the rainy season is followed by two to three months period of cold, dry Harmattan from the Sahara Desert (Sharu *et al.* 2013; AbdulKadir *et al.* 2015). The soils here generally developed in large part on acidic metamorphic rocks, characterized by low activity kaolinitic clay. The relief is between 300 to 900 m. Vegetation is typical of the Northern Guinea savannah (AbdulKadir *et al.,* 2013). Rain-fed and livestock keeping is the predominant agriculture activity in this area (Musa and Shaib, 2010; Concha *et al.* 2013).

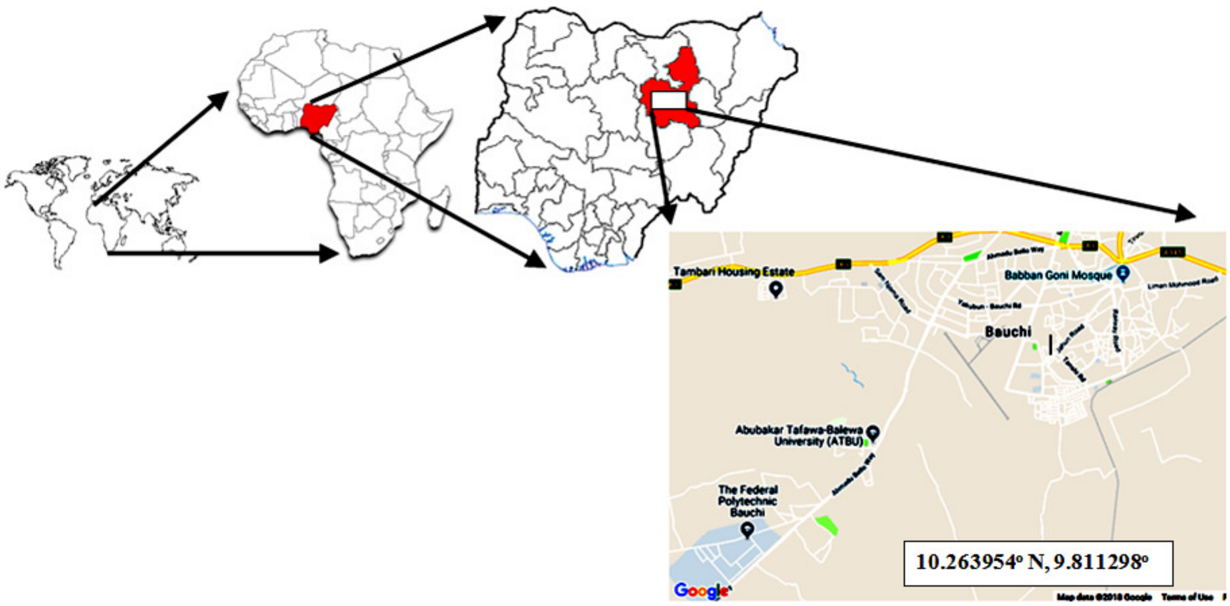

Figure 1: Map of the study area

Mushrooms Collection and Identification: The mushrooms were collected at the onset to the end of the rainy season (i.e., from late month of May to late October) (Brundrett, 1996). The hunting of mushrooms was conducted twice a week. The entire study area was searched for in details and the place where the mushrooms were found to grow were identified as their Microhabitats. Mushrooms at different stages of growth were handpicked; photographed at different resolutions and their Microhabitats and the month in which they were found was recorded (Vishwakarma *et al.,* 2017). The abundance of different species was recorded as the frequency at which the sporocarp was found in time and space rather than the head-count of individuals. Total count of individuals was avoided because some of the species were short-lived and bloomed with over whelming large number of individuals that might not be possible to count. Species identification was archived by carefully examining the attributes of the sporocarps such as colour, shape, size, texture of the cap; and presence or absence of gills, etc. The information was compared with description obtained from Brundrett (1996), and the following websites: http://www.mushroom.world/

mushrooms/list; https://mycorrhizas.info/ecmf.html; and http://www.mushroomxpert.com/agaricus_augustus.html

Data Analyses: T-Test was carried out using XLSTAT version 2018.1. The statistical software Past version 3.20, (2018) was used to calculate the Diversity Indices. The Shannon-Wiener Diversity Index and Simpson's Index were calculated as follows:

Shannon-Wiener Diversity Index, H:

$$H = \sum_{i=1}^{S} - (P_i * \ln P_i)$$

Where:

H = the Shannon diversity index

P_i = fraction of the entire population made up of species i

S = numbers of species encountered

∑ = sum from species 1 to species S (Shannon and Weaver, 1949).

Simpson's Index of diversity, D:

$$D = \frac{\sum n\,(n-1)}{N\,(N-1)}$$

Where:

D = the diversity index

n = the number of individuals in a particular species

∑ = the sum of

N = the total number of organisms

Simpson's Index of Diversity says: D = 1 – D (a higher value indicates higher diversity) (Simpson, 1949).

RESULT

Mushroom Species Composition and Their Distribution: A total of 31 different species of edible mushrooms were found in the study area (Figure 2; Table 1), belonging to 13 different families. The Agaricaceae family is the dominant, which has a total of 13 species; followed by Lyophyllaceae (6) and then Polyporaceae (3). The rest of the families were represented mostly by a single species. The microhabitats where these mushrooms were found include **Arable Lands** currently under cultivation, abandoned **Fallow** lands, soils around dead **Tree stumps**, decaying **Wood**s and 14 different **tree species**. Most of the mushroom species were restricted to only one or two habitats. *Chlorophyllum rachodes* was found in 6 different habitats, which is the most diverse species by the number of different habitats. It is followed by *Bovista colorata, Bovista plumbea, Calvatia cyathiformis and* Termitomyces *robustus*, which were found in 5 different habitats.


Agaricus augustus
Aleuria aurantia
Agaricus subrufescens
Termitomyces reticulatus
Tricholoma terreum
Termitomyces eurrhizus
Agaricus impudicus
Agaricus bitorquis
Termitomyces sp.1
Termitomyces robustus
Termitomyces microcarpus
Chlorophyllum brunneum
Coprinus micaceus
Lentinus trigrinus
Lentinus concavus
Pycnoporus cinnabarinus
Phallus indusiatus
Hypomyces lactifluorum
Cotylidia aurantiaca
Pleurotus cystidiosus
Termitomyces sp.

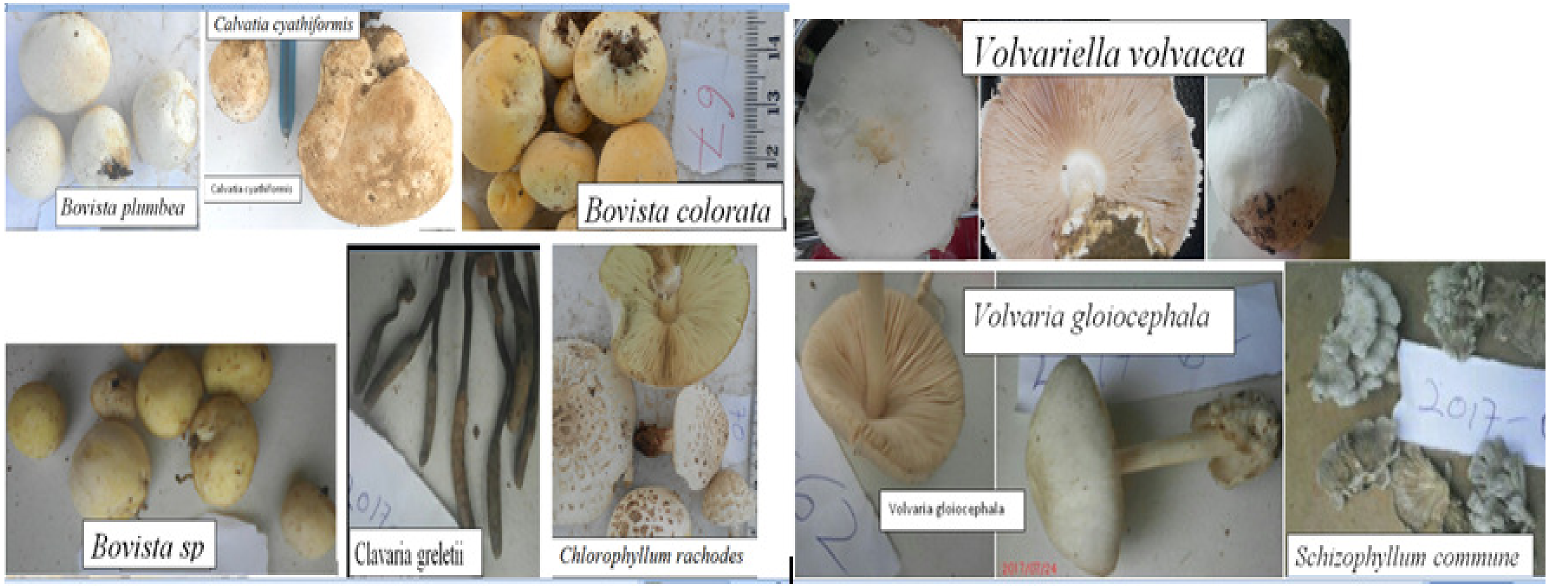

Figure 2: Pictures of the edible mushrooms found in the study area

Out of the total 31 species, 21 species were found in the year 2016 and 24 species in 2017, while only13 species were found in both 2016 and 2017 (Table 1). However, the difference in number of species between 2016 and 2017 was not statistically significant (p-value = 0.961). The appearance and the abundance of the sporocarps of different mushroom species also differ in different months of the rainy season (Table 1). Most of the species were found and are more abundant in the months of June, July and August. In addition, while some species were found only within a particular month, some were found across 2-4 months.

Table 1: Edible mushroom species composition and their distribution in time

Family	Species	No. of Habitats	Month in which `present	Freq. 2016	Freq. 2017	Reference on Species edibility
Agaricaceae	*Agaricus augustus*	1	August - September	0	16	Boa, (2006)
	Agaricus bitorquis	1	June - July	4	3	Zakhary *et al.,* (1983)
	Agaricus impudicus	3	June - July	5	1	Knudsen and Vesterholt, (2012).
	Agaricus subrufescens	1	August	0	1	Chen and Wu, (1984)
	Bovista colorata	5	June - July	12	6	McKnight and McKnight, (1987)
	Bovista plumbea	5	June - July	9	15	McKnight and McKnight, (1987)
	Bovista sp	1	June - July	0	1	McKnight and McKnight, (1987)
	Calvatia cyathiformis	5	June - July	6	4	Bates, (2004)
	Chlorophyllum brunneum	2	August	2	0	Desjardin *et al.,* (2015)
	Chlorophyllum rachodes	6	June - August	24	112	Vellinga *at el.,* (2003)
	Coprinus micaceus	1	June - September	1	0	Smith, A.H. (1975)
	Lycoperdon perlatum	2	June	0	6	Kuo, (2007)
	macrolepiota procera	3	July	8	2	Kirk *et al.,* (2008)
Clavariaceae	*Clavaria greletii*	3	July - August	6	2	Ammirati *et al.,* (1987)
Pyronemataceae	*Aleuria aurantia*	2	August	4	6	Yao and Spooner, (1995)
Hypocreaceae	*Hypomyces lactifluorum*	1	July	1	0	Boa, (2004)
Lyophyllaceae	*Termitomyces eurrhizus*	2	July	2	6	Manna et al., (2015)
	Termitomyces microcarpus	2	June-July	6	2	Manna et al., (2015)

	Termitomyces reticulatus	3	July - August	0	15	Manna et al., (2015)
	Termitomyces robustus	5	July - August	2	15	Manna et al., (2015)
Phallaceae	*Phallus indusiatus*	1	June	1	0	Boa, (2004)
Pleurotaceae	*Pleurotus cystidiosus*	1	June	1	0	Panda *et al.,* (2017)
Pluteaceae	*Volvaria gloiocephala*	1	July - August	0	4	Davis *et al.,* (2012)
	Volvariella volvacea	1	August	3	1	Ding et al., (2001)
Psathyrellaceae	*Coprinellus micaceus*	1	June - August	3	12	Boa, (2004)
Podoscyphaceae	*Cotylidia aurantiaca*	1	August - September	0	2	Boa, (2004)
Polyporaceae	*Lentinus concavus*	1	August	2	0	Boa, (2004)
	Lentinus trigrinus	2	June - September	5	0	Boa, (2004)
	Pycnoporus cinnabarinus	1	July - September	0	6	Boa, (2004)
Schizophyllaceae	*Schizophyllum commune*	1	August - September	0	4	Ruán-Soto *et al.,* (2006)
Tricholomataceae	*Tricholoma terreum*	1	August	0	3	Lamaison and Polese, (2005)

Mushroom Distribution and their Microhabitats: The 31 edible mushroom species were found in 18 different microhabitats (Table 2). The highest species richness (15) and species diversity (Shannon Diversity index, SDI: 2.54) was found under *Parkia biglobosa* tree. The second was *Tamarindus indica*, having 8 species with 1.95 SDI; followed by Decaying Wood where 6 different mushroom species were recorded and with SDI of 1.57. Lowest species richness was found in *Anogeissus leiocarpa,* Arable Land, *Combretum nigricans, Duranta erecta, Gmelina_arborea,* and *Vitellaria paradoxa;* each having only one mushroom species. Collectively, the exotic trees habited 8 mushroom species, while the indigenous trees habited 18. In addition, indigenous trees has significantly (p-value = 0.0001) more mushroom abundance than the exotic trees. Some of the mushroom species were found to be peculiar to only one habitat, i.e., they were found only within that habitat. Decaying Wood has the highest peculiar species, which were 5. They include *Cotylidia aurantiaca, Lentinus trigrinus, Pleurotus cystidiosus, Pycnoporus cinnabarinus* and *Schizophyllum commune.* Fallow have 4 species (*Agaricus subrufescens, Bovista sp, Phallus indusiatus* and *Tricholoma terreum*), followed by *Parkia biglobosa* that has 3 (*Agaricus augustus, Coprinus micaceus* and *Termitomyces sp.2*). Two species (*Agaricus bitorquis and Coprinellus micaceus*) were peculiar to the collective exotic trees, while 18 species were peculiar to the indigenous trees.

Table 2: The microhabitats of the edible mushrooms, their species richness and diversity

Habitat	Species richness	Simpson Diversity	Shannon Diversity	No. of peculiar or Unshared species
Adansonia digitata	2	0.38	0.56	1

Anogeissus leiocarpa	1	0	0	0
Arable Land	1	0	0	1
Combretum nigricans	1	0	0	0
Dalbergia sissoo	2	0.5	0.69	0
Daniellia oliveri	2	0.44	0.64	0
Duranta erecta	1	0	0	0
Ficus sycomorus	5	0.59	1.17	0
Fallow	5	0.59	0	4
Gmelina arborea	1	0	0	1
Khaya senegalensis	3	0.67	1.10	0
Mangifera indica	3	0.59	0.97	0
Parkia biglobosa	15	0.91	2.54	3
Tamarindus indica	8	0.85	1.95	1
Thevetia neriifolia	2	0.5	0.69	1
Tree stump	3	0.36	0.66	1
Vitellaria paradoxa	1	0	0	0
Wood	6	0.76	1.57	5

DISCUSSION

Mushroom Species Composition and Their Distribution : Survey of the study area revealed that it contain suitable microhabitats for diverse edible mushroom species, which comprises mostly of those edible mushroom species belonging to the family Agaricaceae, Lyophyllaceae and Polyporaceae. Most abundant species are *Bovista colorata, Bovista plumbea, Chlorophyllum rachodes* and *Termitomyces robustus.* Adeniyi *et al.,* (2018) and Andrew *et al.,* (2013) have reported the presence some of these species in sub-humid Nigerian tropical rain forest and Mount Cameroon. This suggests that many of the mushroom species can thrive in a wide range of climatic gradients. While some species were restricted only to one microhabitat, some were found in different microhabitats. These include *Bovista colorata, Bovista plumbea, Calvatia Chlorophyllum rachodes, cyathiformis and* Termitomyces *robustus*. The appearance of the mushrooms species in a particular month of the rainy season depends on the species. Some appeared and disappeared in the early part of the season while others appeared toward the end of the season. Most of the species appeared around the middle of the season when moisture availability was highest and temperature was lowest. However, some species were present almost throughout the season although their abundance varies with months. There were also inter-annual fluctuations of species richness and abundance as observed in studies by Adeniyi *et al.,* (2018) and (Egli, 2011). Inter-annual and inter-monthly variations in mushroom fruiting patterns within the rainy season is believed to be as a result of changes in meteorological conditions, especially rainfall and temperature (Alday *et al,* 2017; Vishwakarma *et al.,* 2017; Svenning *et al.,* 2018).

Mushroom Distribution According To Microhabitats: The microhabitats of the edible mushrooms in the study area include Arable Lands currently under cultivation, abandoned Fallow lands, soils around dead Tree stumps, decaying Woods and 14 different living tree species. More important in terms of species richness and abundance are *Parkia biglobosa*, *Tamarindus indica* and decaying Wood. However, the importance of other habitats with low species richness should not be under estimated because some of the mushroom species they habited are peculiar to them only and may not be found anywhere else. Trees are known to have substantial impact on mushroom diversity and fruiting pattern. The trees affect ambient temperature and relative humidity through shading and reduced moisture loss from under their crowns, depending on the architecture of their crown (Gabel and Gabel, 2007). Trees also amplify rainwater by canopy interception and stem flow, and therefore provide more moisture in the soil within their crown cover than outside. As a result of these, the distribution and productivity of wild edible mushrooms are also affected, whose environmental requirements differ among different species (Egli, 2011; Alday *et al,* 2017; Vishwakarma *et al.,* 2017). However, the magnitude by which trees in the dry lands influence the meteorological conditions at a micro-scale, under their canopy depends on their crown morphological attributes like the size, density, depth of their crowns and leaf density (Buba, 2015a; Buba, 2015b). These features should be expected to vary among different tree species and individuals. These can partly explain the reason some trees species support more species of mushrooms than others. Saprophytic mushrooms species can also thrive under tree canopy as a result of more abundant dead ligneous litter cover provided by the latter under their crowns (Schmit, 2005). Another way by which trees affect the composition and distribution of edible mushrooms species is through mutualistic associations with mycorrhizal edible mushrooms. The edible mushrooms species that are capable of forming positive association with tree species depend on their hosts for phosynthates, while the tree benefit more efficient supply of water and minerals by the fungi. However, the rate of photosynthesis by trees depends on tree species in question and their physiological state, hence different tree species will be expected to perform in different way with respect to different mycorrhizal species and therefore mushrooms fruiting pattern (Egli, 2011; Adeniyi *et al.,* 2018). It is also possible that many of the above-mentioned factors may interact to form various pattern of mushroom species abundance, distribution and composition with respect to different tree species and even among individual trees of the same species (Egli, 2011). Decaying Wood and soil around dead Tree stump also formed suitable habitats for some edible mushroom species and some of these species were peculiar to them only. It is well known that distribution of mushrooms differs among different substrates due to their differences in nutritional composition and moisture availability (Adeniyi *et al.,* 2018; Svenning *et al.,* 2018). Schmit, (2005), reported that most of wild saptrophytic edible mushrooms are found on variety of ligneous substrates from which they obtain nutrients and water for growth. Intensive wood harvest will therefore lead the decline of edible mushroom diversity. In addition, soils around dead tree stumps contain high amount of degraded nutrients and organic matters that give them the capacity to retain high moisture, thereby forming favourable environments for growth of some edible mushroom species (Adeniyi *et al.,* 2018). This study also revealed that exotic trees species that were introduced mainly as ornamental plants are important habitats for edible mushroom. The exotic trees habited some of the mushroom species that are common to other native trees, but some of the mushroom species were peculiar to the exotic trees only. It might be possible that those mushroom species that were peculiar to exotic trees were introduced alongside their host from their original habitats. The exotic trees can therefore increase local edible species diversity. Cultivation also has effect on edible mushrooms diversity as revealed by this study. Some of the species were found to be peculiar either to the cultivated lands or the fallow. This suggests that the presence of both cultivated lands and fallow in a landscape will increase the regional diversity of edible mushrooms. This is contrary to some findings (Andrew *et al.,* 2013; Baral et al., 2015; Adeniyi *et al.,* 2018) that human interference through cultivation leads to decline in the species richness and abundance of mushrooms in general. However, more species diversity was in the fallow than the cultivated lands, hence in the complete absence of fallow mushroom diversity will greatly decline.

Implication for Optimal Exploitation: The result of this study has important information that can be an indispensable guide for proper exploitation of edible mushrooms in this region and elsewhere, which rarely exist before. Firstly, the checklist of edible mushroom species with their photographs is provided so that the composition of the edible mushrooms of area can be known. Secondly, the microhabitats where these mushrooms can be found are identified. They are Arable Lands currently under cultivation; abandoned Fallow lands; soils around dead Tree stumps; decaying Woods; and 14 different living tree species. Some of these habitats contain some species that can only be found in them; hence, to maintain the maximum diversity of these edible mushrooms, these habitats should be conserved. Some of the species were found to be peculiar only to exotic tree species. In this aspect, introduction of exotic trees and shrubs should, as ornamental plants should therefore be encouraged. Thirdly, inter-annual variation in mushroom fruiting patterns was observed, i.e., some of the species can completely disappeared in a particular year and appear in another. For a continual use of these species, domesticating them is therefore necessary. The fruiting pattern of these mushrooms species also varies with months within the rainy season. Mushroom hunters should therefore look for different species in their particular fruiting months.

CONCLUSION

The study area is rich in diverse edible mushroom species, which comprises mostly of those species belonging to the family Agaricaceae, Lyophyllaceae and Polyporaceae. The microhabitats of these mushrooms include arable lands currently under cultivation; abandoned fallow lands; soils around dead tree stumps;

decaying woods; and 14 different living tree species. More important in terms of species richness and abundance among these habitats are *Parkia biglobosa*, *Tamarindus indica* and decaying wood. Some mushroom species were found only in one habitat. The fruiting pattern of the different mushrooms species changes in different months of the rainy season. Inter-annual fluctuations of species richness and abundance were observed. This study revealed that exotic trees species that were introduced mainly as ornamental plants are important habitats for edible mushroom with some of the mushroom species being peculiar to them. The presence of both cultivated lands and fallow in the landscape increase the diversity of edible mushrooms. The result of this study has important information that can be an indispensable guide for proper exploitation of edible mushrooms in this region and elsewhere. This is by providing the checklist of edible mushroom species with their photographs; identifying the microhabitats where these mushrooms can be found; revealing the inter-annual and months variation in mushroom fruiting patterns of different species; and the importance of cultivation, fallow and exotic tree species in maintaining diversity of mushroom.

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