



Diversity and domestication of mushroom species in the Atewa forest reserve and Bia Biosphere, Ghana

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ABSTRACT

Edible mushrooms commonly found in forest reserves are important for food security but they are underutilized in Ghana. The Atewa forest reserve in the Eastern Region and Bia Biosphere in the Western Region are among the largest forest reserves in Ghana. However, human activities including illegal mining activities pose a threat to the existence of the rich mushroom diversity within these forests. The objective of this study, therefore, was to collect, characterize and domesticate mushrooms from the Atewa forest reserve and the Bia Biosphere. Wild mushroom samples were randomly photographed, collected, dried and stored. Edible and wild mushrooms were characterized morphologically and compared with literature. A total of 86 mushroom samples (comprising 45 from the Atewa forest reserve and 41 from the Bia Biosphere) were collected and identified. The two forest reserves contained a rich diversity of wild mushrooms namely: *Cookeina speciosa*, *Marasmiellua inoderma*, *Auricularia cornea*, *Daldinia concentrica*, *Pleurotus* sp. *Polypores*. Cultivated *Auricularia auricula* strain AUAT recorded the highest ash content (16.70%) while cultivated *Ganoderma* sp. strain GLB recorded the lowest ash content (5.12%). On the other hand, cultivated *Pleurotus ostreatus* strain POB recorded the highest fat content of 19.88% and cultivated *Pleurotus saju-caju* strain PSCAT gave the least value of 12.02%. Cultivated *Auricularia auricula* strain AUAT again recorded the highest protein value of 33.38% while wild *Ganoderma* sp. Strain GLB had the least protein value. A total carbohydrate level of 64.22% was observed in cultivated *Ganoderma* sp. strain GLB. The highest oxalate content of 30.93 mg/100 g was recorded in cultivated *Pleurotus ostreatus* strain EM1 with cultivated *Auricularia auricula* strain AUAT being the least value of 4.73 mg. A high phytate value of 149.35 mg was observed in cultivated *Auricularia auricula* strain AUAT and cultivated *Pleurotus saju-caju* strain PLAT showed the lowest value of 31.60 mg/100 g. The present findings provide considerable data on fungal diversification, conservation and domestication as well as a reference point for future studies.

Introduction

Wild edible mushrooms are valuable non-wood forest resources, cherished by many communities in the world [1]. Mushrooms

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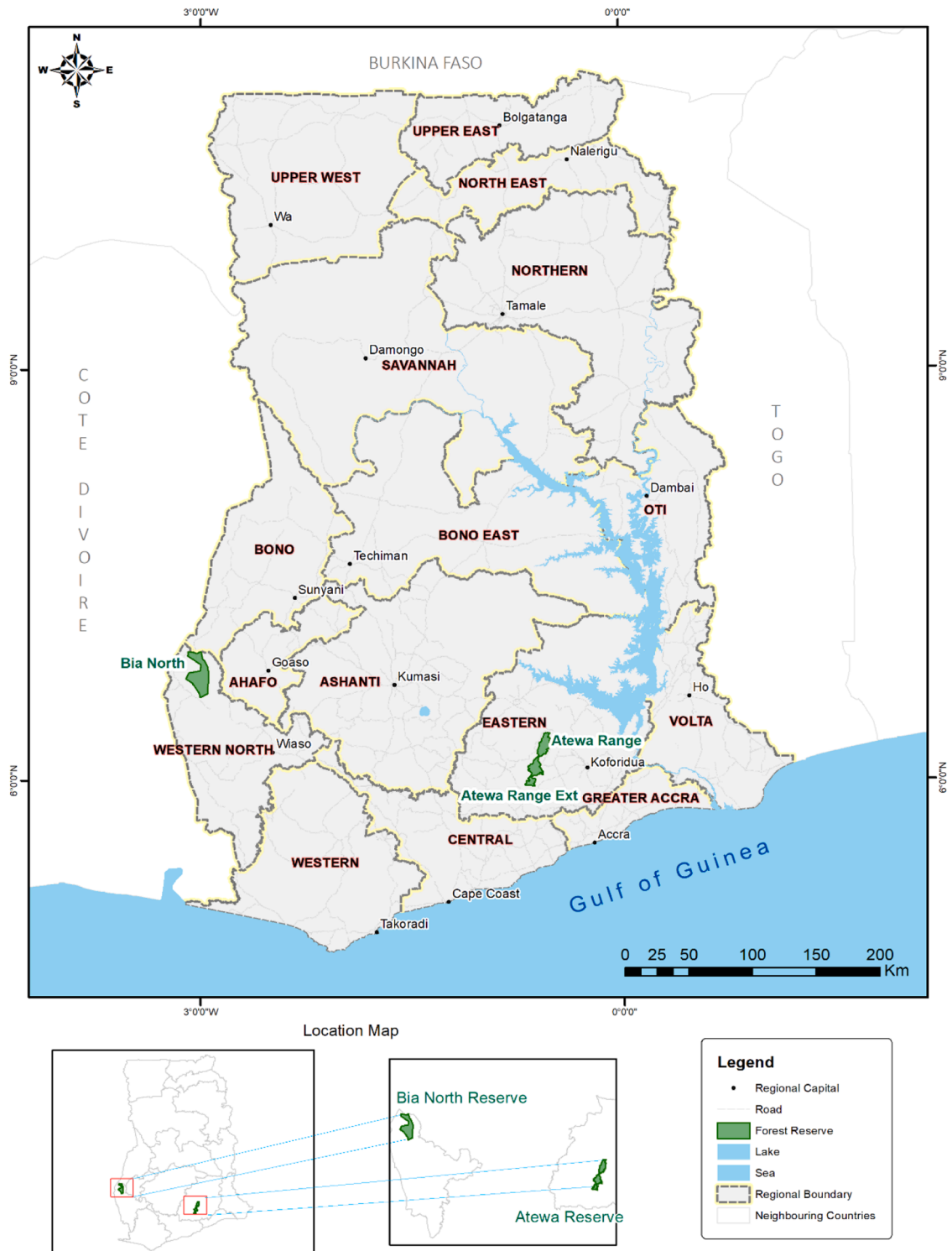


Fig. 1. Map showing study areas (Atewa and Bia Forest Reserves)
 Source: Geography Department, University of Ghana, Legon.

have important social, economic and ecological roles among indigenes of most West African countries. Various edible species are used in many traditional meals especially within the rainy season when they occur naturally in the wild. Ghana is a West African country bordering on the Gulf of Guinea, Côte d'Ivoire to the west, Burkina Faso to the north, Togo to the east, and the Atlantic Ocean to the

south (Fig. 1). There are several forest reserves within the territories of Ghana. Statistics in Ghana show that the country's entire forest cover which remained at 8.2 million hectares at the beginning of the 20th century has dwindled to roughly 1.6 million hectares. It is projected that its forest resource in the next 23 years will be lost if correct measures are not put in place [2]. Given this alarming situation in terms of the rate of desertification, the rationale for this study is to characterize the mushroom germplasm in some forests in Ghana with the view of conserving these mushrooms under threat of which some will serve as raw materials for the nutraceutical and functional food industries. Mushrooms are traditionally collected and used by indigenes of the Southern part of Ghana especially inhabitants of the forest zones. The local populations generally consider mushrooms as alternatives for animal protein and also refer to mushrooms as meat for the underprivileged.

The oyster mushroom is known to be the second most widely cultivated mushroom in the world. The *Agaricus bisporus* is in the first position. *Pleurotus* species are prevalent and extensively grown in a lot of countries around the world, especially in Asia, America as well as Europe due to their simple, low-cost production technology and high biological efficiency [3]. All *Pleurotus* species are effective degraders of lignin that can grow on a broad variety of agricultural wastes and grow at a wide range of temperatures. They have high economical, ecological, and medicinal values. Moreover, they can colonize and degrade a large variety of lignocellulosic materials and similar by-products that are produced by agricultural, forest, and food processing industries.

Awareness of the consumption and cropping of edible mushrooms is about 1000 years ago, nonetheless, it has become popular recently owing to consumer needs about well-being upkeep. Edible mushrooms are highly thought of as foods that have high nutritional value therefore they are loaded with fibre, protein, and minerals, and with very minimal fat content [4].

The medicinal properties of mushrooms are credited to the occurrence of bioactive compounds such as vitamins, polysaccharides, and secondary metabolites in their fruiting bodies. Several of them possess antioxidant properties that are referred to repeatedly to be the key aspect of their observed beneficial effects. Polyphenols and carotenoids, abundant in the fruiting bodies of mushrooms, are efficient antioxidants in biological systems. Also, polyphenols have been reported to interfere with the initiation and progression of cancer, anti-ageing, anti-inflammatory, and brain protection effects against cardiovascular diseases and lipid peroxidation chain breakers [5–8].

The collation of information and a compendium on the identification of these mushrooms have not been fully documented. According to reports by some authors, the identification of mushrooms is a huge challenge owing to limitations such as limited reference samples, and skill, particularly in the tropics [9]. There is also so much indigenous knowledge available among indigenes on the uses of mushrooms that is yet to be tapped fully. This study focuses on the collection, identification, documentation, and domestication of indigenous mushrooms from two forest reserves in Ghana.

Materials and methods

Study areas

Fig. 1 shows the map of Ghana highlighting the study areas, Atewa and Bia forests. Atewa is a unique tropical rainforest. It is the crown jewel in Ghana's reserves, with distinctive upland forest, dense woodland and natural clearings, marshy grasslands and clear mountain streams, with swamps and thickets on the high plateaus. Atewa is also one of the largest remaining blocks of tropical forest in West Africa, home to significant populations of extremely rare plants and animals. Atewa supports an exceptional number of plants not found elsewhere in Ghana, due to the diverse topography of the misty hill summits [10].

The Bia National Park and Bia Resource Reserve constitute a twin conservation area. It is found in the transitional zone between moist-evergreen and moist semi-deciduous forest types. It covers a total area of 305.62 km² of the original National Park, which was later divided into. 277.92 km² Bia Resource Reserve and the other 77.7 km² represent the National Park. It is the only Biosphere Reserve in the country [11].

Physical and photographic characterization of edible and wild mushrooms

The different edible and wild species of mushrooms to be identified from the survey studies within the two regions were studied for the variations in physical characteristics. The collected samples were grouped into their major taxa and then dried using a locally fabricated field drier. They were then kept in a herbarium. Photographic images of the different mushrooms were taken using a high-definition camera (Nikon D850, Tokyo, Japan). Information on location, ephemeral characteristics such as veil remains, removable scales, fibrils, volva, etc as well as diagnostic features, were also documented. Different edible and wild species of mushrooms identified from the survey studies within the two regions were studied for the variations in physical characteristics such as the cap type, presence of gills or pores, presence of volva etc. The descriptions were compared to literature information and the genus identified [12–15].

Laboratory studies on mushroom features

The following features were examined using a hand lens (United Scientific Supplies, USA) and light microscopes (Model: Max II 1202.4000, NO 02616, United Kingdom). Cap: shape-margin and size in longitudinal section and vertical section, color and ornamentation. Hymenophore (gill, or pores): shape from below, attachment, edge of gills, color and spore print. Stipe: insertion, consistency, size, shape, color and ornamentation. Flesh: thickness, color, smell, and taste [16,17].

Experimental location and design

The experiments were conducted in the Mushroom Research unit, at the CSIR-Food Research Institute in Accra, Ghana. The experiments were arranged in a randomized complete design with three to five replications depending on the experiment.

Culture preparation

Tissue cultures of five (5) known and identified mushroom strains were carried out on Potato Dextrose Agar (Oxoid, CMO139 Hampshire England). The mycelium discs (1 cm diameter) of each mushroom were placed in Petri dishes containing each culture medium (20 mL) under aseptic conditions and incubated at 28 °C in the darkness. The diameter of the mycelium expansion was measured every 2 days for 8 days. Spawns of these mushrooms were prepared on sorghum grains as described by others [18,19]. The various mushroom species were grown on Potato Dextrose Agar (PDA) and incubated at 26 °C, 28 °C, and 30 °C, and the spawn was incubated at 26–28 °C and 60–65% relative humidity.

Spawn preparation

The mushroom spawns were made by the use of an adapted process of spawn preparation [11]. They were held in place with rubber bands. The bottled grains were then sterilized in an autoclave (Priorclave, Model PS/LAC/EH150, England) at 121 °C for 1 h at a pressure of 15 psi [20].

Substrate preparation

The substrate used comprised 88% of *Triplochiton scleroxylon* sawdust (Wawa), 2% of Calcium carbonate (CaCO₃), and then 10% rice bran. The moisture content was adjusted to 65% [20–22]. The blend was mixed up meticulously, it was heaped to a height of about 1.5 m and a base diameter of 1.5 m, covered up with a black polythene sheet and composted for 28 days at 30 – 60 °C. The sawdust heap was turned every 4 days to ensure homogeneity. The plastic bag method was used to grow the mushrooms [18,19,20,22].

Proximate analysis

Moisture content was determined using the air-oven method at 105°C as described in the AACC

Method 44–15, (2000). Ash was calculated as follows Approximately 4 g of each mushroom strain was weighed accurately into a silica ash crucible that had previously been ignited, cooled in a desiccator and weighed. The samples were incinerated in a muffle furnace until a light grey ash was obtained, cooled in a desiccator, and weighed (AACC Method 08-01, 2000). The analysis of Fat was done according to AOAC (2005). The standard method of AOAC 2005 was used to determine the protein content. Carbohydrate was calculated as stated by (Raghuramulu et al., [23] and Alam et al., [24].

Antinutrient determination

Dried mushroom sample of 0.2 g was weighed into a 15 mL centrifuge tube. Approximately 10 mL of deionized water was used for extraction, agitated at 300 rpm on an orbital shaker for 1hr and centrifuged at 10,000 rpm for 15 min, according to the method used by Baros et al., [25] and Ramkumar et al., [26].

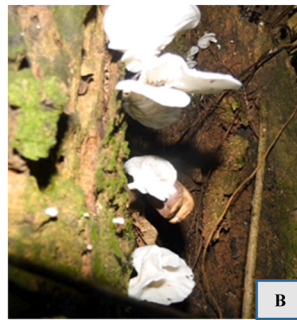
Results and discussion

Mushroom diversity in the atewa forest

Forty-five (45) samples of mushrooms were collected from the Atewa Forest in the Eastern Region of Ghana. Plates A-T represent some photographs of the samples showing their morphological characteristics. Samples such as *Auricularia* and *Daldina* species have been previously found in the Atewa forest [17]. *Psathyrella* sp, *Pleurotus tuber-regium*, *Pleurotus pulmonarius*, *Pleurotus ostreatus*, *Schizophyllum commune* are found in Nigeria, Bénin, Cameroon and Ghana [27]. Mushrooms were recorded to be collected from woodlands such as forests and plantations as well as farmlands and grasslands [27].



(A)(*Clavulina* sp.)



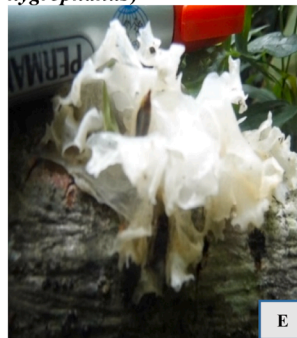
(B)(*Neonothopanus hygrophanus*)



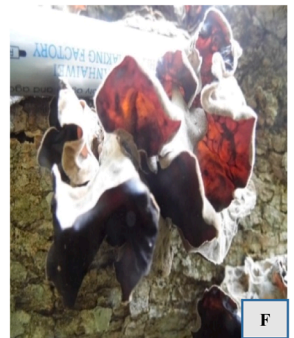
(C)(*Xylaria* sp.)



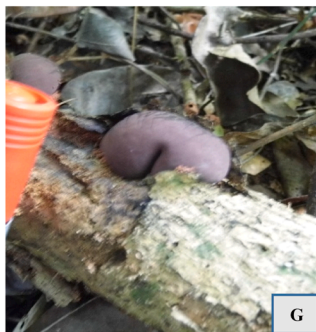
(D)(*Schizophyllum commune*)



(E)(*Flammulina* sp.)



(F)(*Auricularia auricula* strain AUAT)



(G)(*Daldinia concentrica*)



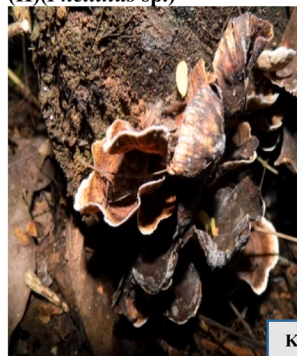
(H)(*Phellinus* sp.)



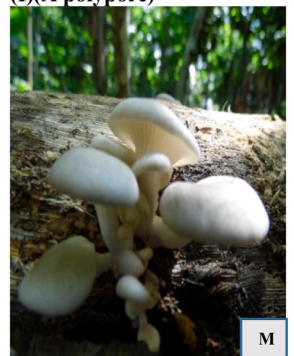
(I)(A polypore)



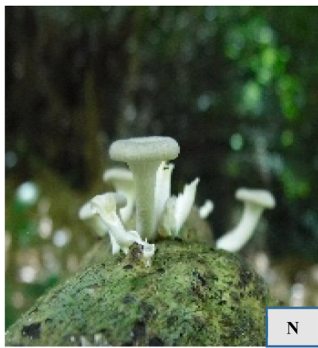
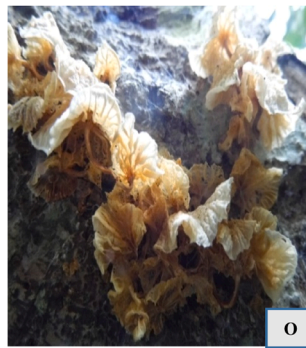
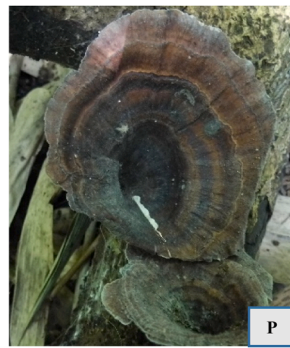
(J)(*Collybia piperata*)



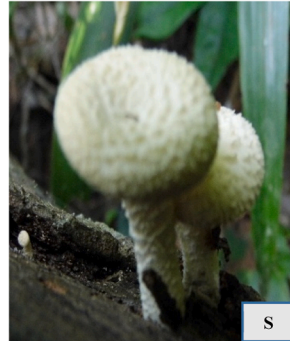
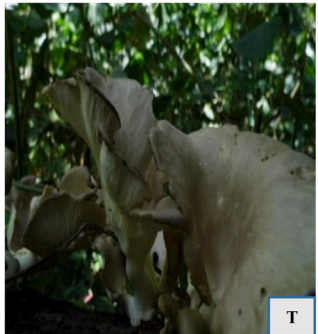
(K)(A Polypore)



(M)(*Pleurotus saju-caju* strain PLAT)

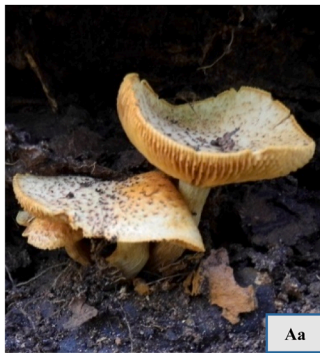
(N)(*Pleurotus* sp. strain POAT)(O)(*Micromphales foetidum*)(P)(*Trametes* sp.)(Q)(Suspected *Galiella rufa*)

(R)(Unknown)

(S)(*Lycoperdon* sp.)(T)(*Pleurotus saju-caju* strain PSCAT)

Mushroom diversity in the Bia forest reserve

Forty-one (41) samples of mushrooms were collected from the Bia forest reserve in the Western Region of Ghana. Below are photographs of some of the samples (Aa-Qq) showing their morphological characteristics. Fig. 2, shows the phylogenetic representation of samples collected from Atewa and Bia forest reserves. Mushrooms collected included those of the Class Agaricomycetes, Basidiomycetes, Sordariomycetes, Pezizomycetes. Order Polyporales, Agaricales, Auriculariales, Russulales, Cantharellales, Hymenochaetales, Agaricales, Xylariales and Pezizales. Some of these mushrooms have been previously discovered by some researchers. [17, 27]. *Ganoderma* was found growing on a decayed stump while *Calvatia* and *Russula* were found growing on debris on the forest ground.



(Aa)(*Russula* sp.)



(Bb)(*Calvatia* sp.)



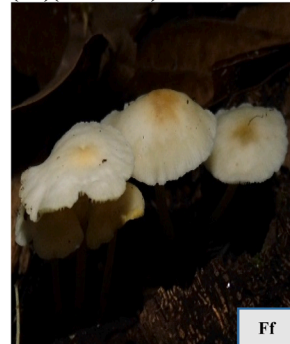
(Cc)(Unknown)



(Dd) (A Polypore)



(Ee)(*Agaricus* sp.)



(Ff)(*Marasmius oreades*)



(Gg)(A Polypore)



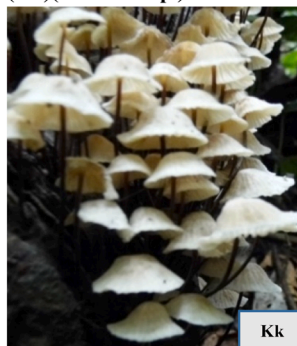
(Hh)(*Cookeina* sp.)



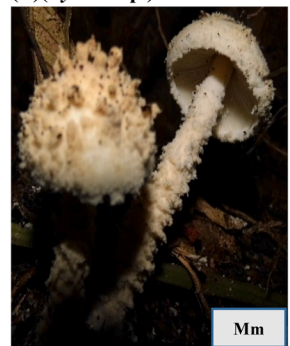
(Ii)(*Xylaria* sp.)



(Jj)(A Puffball)



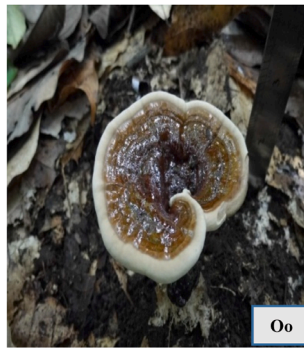
(Kk)(Unknown)



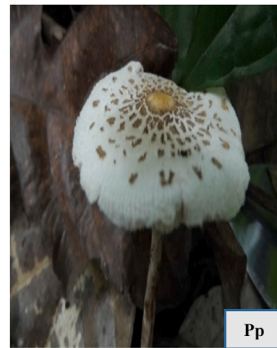
(Mm)(*Lepiota* sp.)



Nn

(Nn)(*Oudemansiella canarii*)

Oo

(Oo)(*Ganoderma* sp. strain GLB)

Pp

(Pp)(*Termitomyces* sp.)

Qq

(Qq)(*Xylaria* sp.)

Growth characteristics of strains on mycological media at three different temperatures

Five edible mushroom strains were selected from the two forests and one control sample was grown on Potato Dextrose Agar (PDA) and incubated at 26 °C, 28 °C and 30 °C. Plate 1 shows freshly inoculated plates of all six strains of mushrooms on mycological media and incubated at 26 °C. The experiment was carried out in triplicates.

The six mushroom strains fully colonized the media after an average of 6 days as shown in Plate 2. The different strains show different patterns and densities of mycelia growth. *Pleurotus ostreatus* strain POB had the densest growth while *Auricularia auricula* strain AUAT had the least dense growth. The growth pattern spanned from fluffy growth which was observed with *Auricularia auricula* strain AUAT then spiral growth which was seen in *Pleurotus saju-caju* strain PSCAT and *Pleurotus saju-caju* strain PLAT (although that of *Pleurotus saju-caju* strain PLAT was denser) to cotton-like which was exhibited by *Pleurotus ostreatus* strain EM1 and leathery growth which was seen in the *Pleurotus ostreatus* strain POB and *Ganoderma* species strain GLB (Plate 2).

Mycelia growth on PDA plates at 26°C

At 26 °C *Pleurotus saju-caju* strain PSCAT covered the mycological media in five days with an average growth rate of 2.73 cm per day. This was followed by *Pleurotus ostreatus* strain POB which colonised the media in six days with an average daily growth rate of 2.63 cm. *Pleurotus ostreatus* strain EM1 also covered the media in six days at an average growth rate of 2.66 cm. *Auricularia auricula* strain AUAT gave an average daily growth rate of 2.75 cm, covering the media in six days and *Pleurotus saju-caju* strain PLAT also covered the media in six days at an average daily growth rate of 2.67 cm. *Ganoderma* species strain GLB on the other hand fully covered the mycological media on the 7th day at an average daily growth rate of 2.67 cm. (Fig. 3).

Mycelia growth on PDA plates at 28°C

At 28 °C *Pleurotus ostreatus* strain, EM1 and *Ganoderma* species strain GLB covered the mycological media in 5 days and at a daily average mycelial growth rate of 2.81 cm and 2.72 cm respectively. Thus making them the fastest-growing strains at that temperature. *Pleurotus saju-caju* strain PSCAT (2.94 cm), *Pleurotus ostreatus* strain POB (2.80 cm) and *Pleurotus saju-caju* strain PLAT (2.90 cm) on the other hand all covered the mycological media in 6 days. *Auricularia auricula* strain AUAT covered the mycological media in 7 days with an average daily growth rate of 2.57 cm, thus making *Auricularia auricula* strain AUAT the slowest strain as shown in Fig. 4.

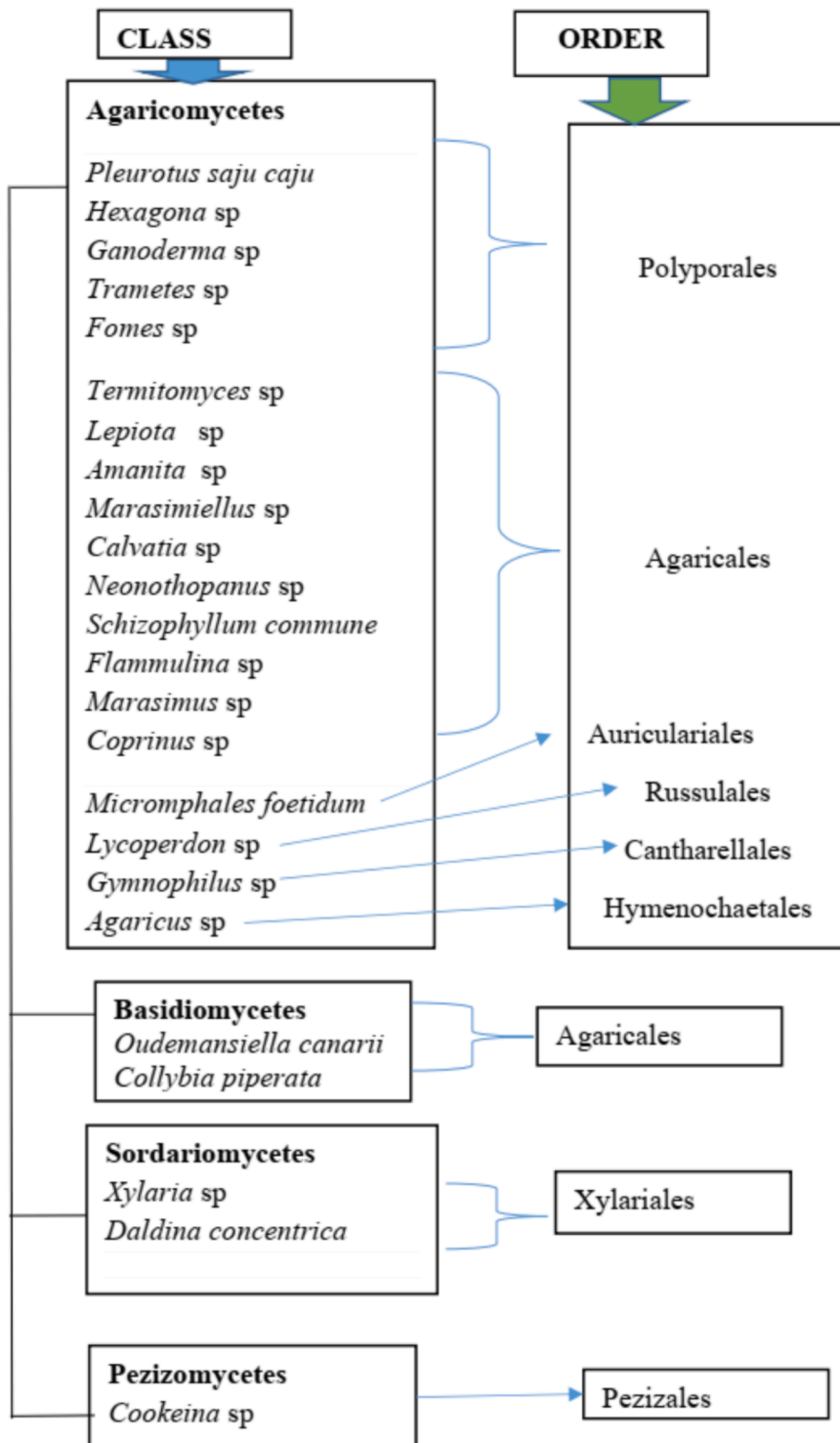


Fig. 2. Phylogenetic representation of samples collected from Atewa and Bia forest reserves wild mushrooms.

Mycelia growth of six mushroom strains on PDA plates at 30°C

At 30 °C, *Pleurotus saju-caju* strain PSCAT was the fastest to cover the nutrient media on the fourth day with an average daily growth rate of 2.84 cm. This was followed by *Pleurotus ostreatus* strain POB and *Pleurotus ostreatus* strain EM1 colonising the media in five days

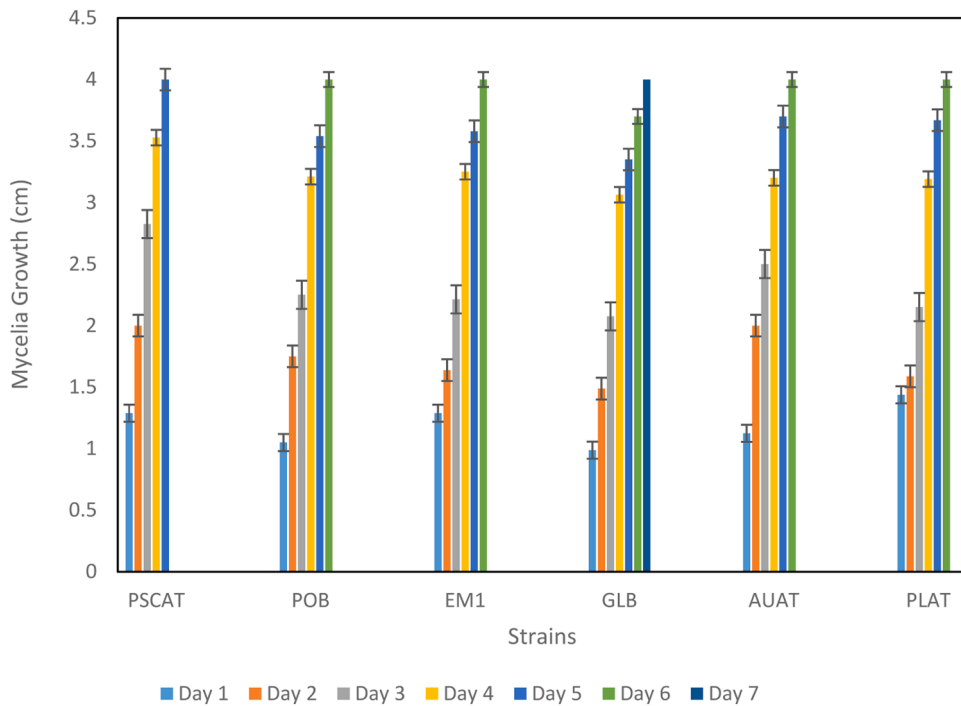


Fig. 3. Mycelia growth of six mushroom strains characteristics on PDA plates at 26 °C.

as shown in Fig. 5, and an average rate of 2.78 cm and 2.86 cm respectively. *Pleurotus saju-caju* strain PLAT took six days to colonise the media at 2.97 cm daily growth. *Ganoderma* species strain GLB and *Auricularia auricula* strain AUAT both covered the media in 7 days.

Apart from *Pleurotus ostreatus* strain EM1 and *Auricularia auricula* strain AUAT which colonized the bags in four weeks, *Ganoderma* sp. strain GLB, *Pleurotus saju-caju* strain PLAT, *Pleurotus ostreatus* strain POB and *Pleurotus saju-caju* strain PSCAT all colonized the bags within three weeks under the same environmental conditions. This was also observed by some researchers showing that the mycelia

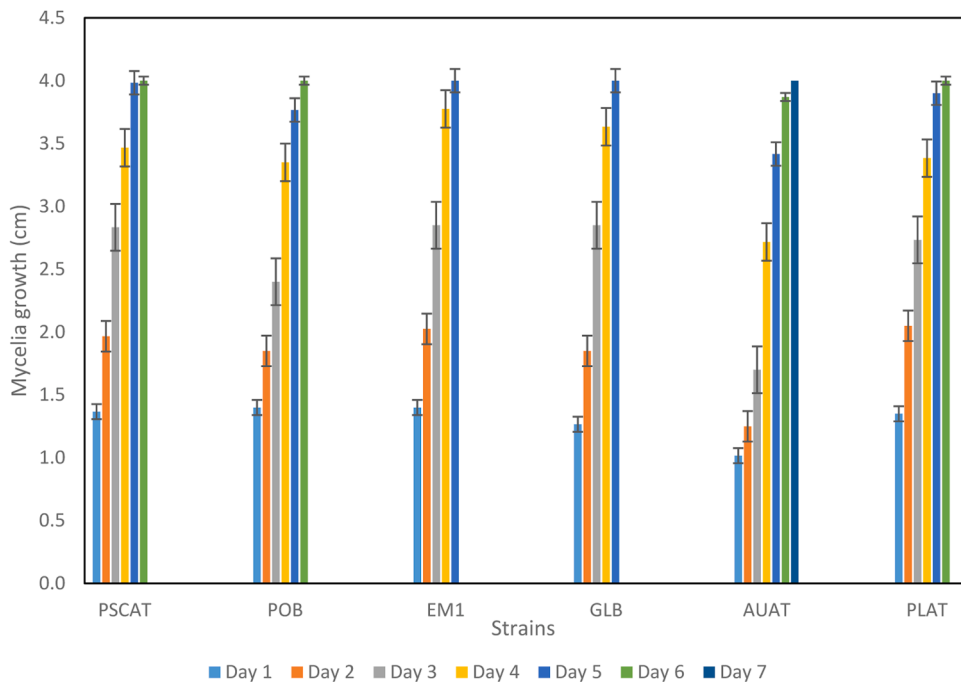


Fig. 4. Mycelia growth of six mushroom strains characteristics on PDA plates at 28 °C.

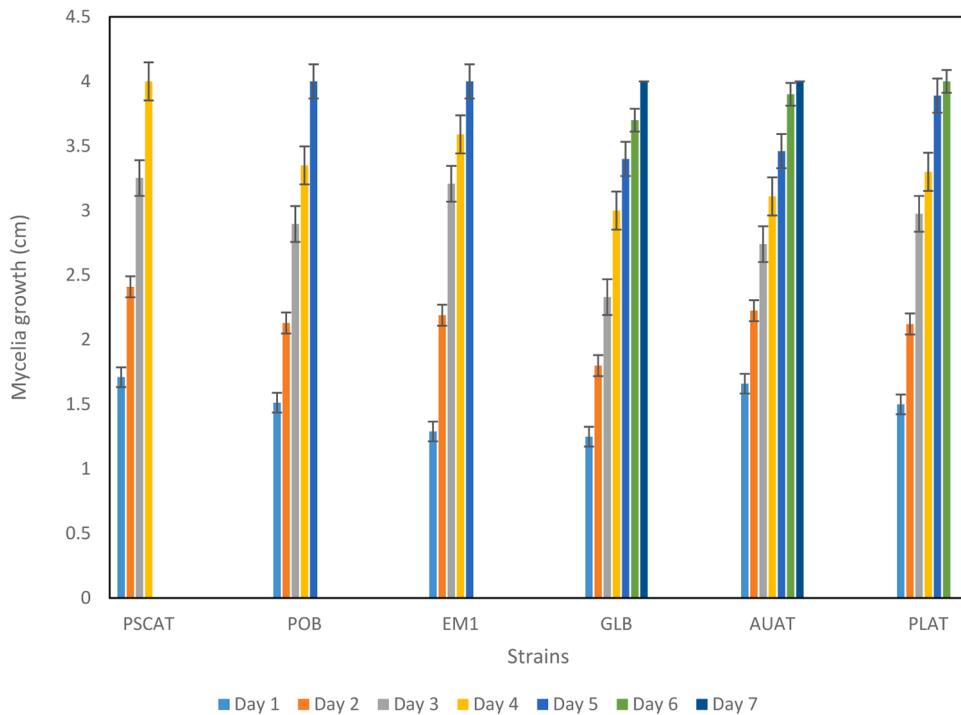


Fig. 5. Mycelia growth of six mushroom strains characteristics on PDA plates at 30 °C.

colonized the substrate for an average period of four weeks [28]. At the end of Week 1 *Ganoderma* sp. strain GLB, which covered 10.15 cm of the bag in the first week, averagely exhibited the fastest growing strain followed by *Pleurotus sajju-caju* strain PLAT, *Pleurotus ostreatus* strain POB, *Pleurotus sajju-caju* strain PSCAT, *Pleurotus ostreatus* strain EM1 and *Auricularia auricula* strain AUAT respectively. For all the strains the growth rate reduced gradually as they entered the second week (Table 1). There was a further decrease in the third and fourth weeks as well. This is likely due to the degradation of the substrates by the mycelia thus leading to the production of mushroom fruitbodies. This is supported by what was reported by others where the mycelial growth rate declined as the strains colonized the substrates [29].

Fruit body flushes

Fruitbody flushes of the various strains of mushrooms are presented in Plates 4a-9. Plate 4a shows young fruitbodies of *Ganoderma*

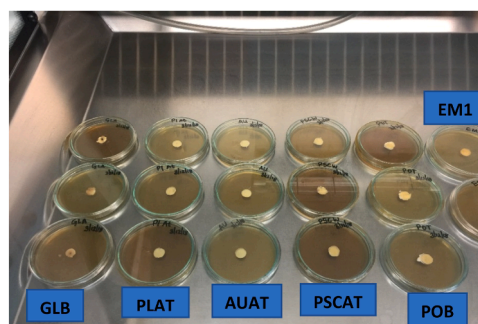


Plate 1. Freshly inoculated plates of six mushroom strains.

Strains

- Pleurotus ostreatus* strain EM1
- Ganoderma* species strain GLB
- Pleurotus sajju-caju* strain PSCAT
- Pleurotus ostreatus* strain POB
- Pleurotus sajju-caju* strain PLAT
- Auricularia auricula* strain AUAT.

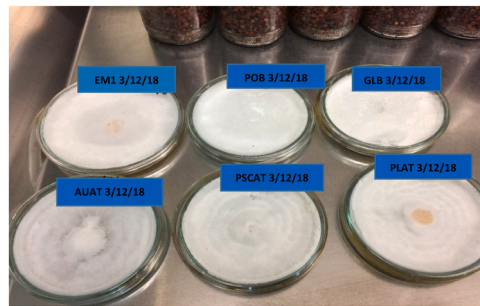


Plate 2. Plates showing growth of the different strains.

Table 1
Mycelial growth rate of six mushroom strains growing in compost bags.

Period of colonization (Weeks)	STRAINS USED (n = 5) cm					
	GLB	AUAT	PLAT	POB	EM1	PSCAT
1	10.15±1.08	8.29±0.75	10.08±0.14	9.45±0.91	8.19±1.06	9.01±0.73
2	5.67±0.52	5.76±0.47	6.95±0.19	8.58±1.09	3.89±1.09	8.49±0.71
3	3.67±0.75	3.72±0.42	2.64±0.49	2.61±0.90	4.2 ± 0.47	3.69±0.79
4	NA	2.35±0.92	NA	NA	3.32±0.54	NA
Growth Rate/day	0.93	0.72	0.94	0.98	0.7	1.01

NA: Fully colonized but not thickened.

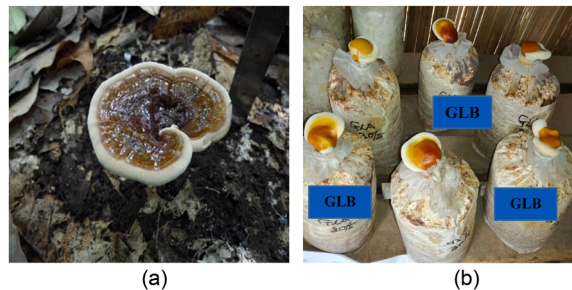


Plate 4. a. A young *Ganoderma* sp. strain GLB growing in the wild. b: Young Fruit bodies of *Ganoderma* sp. Strain GLB fruiting after three months of incubation.

sp. strain GLB growing from the substrate compost bag. A characteristic feature of a young *Ganoderma* sp. fruitbody is the white edge of its cap. This turns brown as the fruit body matures. The surface of the cap has a glossy feel and a shiny look. Plate 4b shows the *Ganoderma* sp. growing in its natural habitat. It was found growing on a rotten tree stump. Plate 5a shows the pictorial view of flushes of *Pleurotus saju-caju* strain PSCAT growing on sawdust. A distinctive feature of this strain is the curvy ends of the fruitbody cap and its slightly grey color. And Plate 5b is flushes of *Pleurotus saju-caju* strain PSCAT growing in the wild. Plate 6a shows flushes of *Pleurotus saju-caju* strain PLAT growing on sawdust, while Plate 6b shows *Pleurotus saju-caju* strain PLAT growing in the wild. This strain is

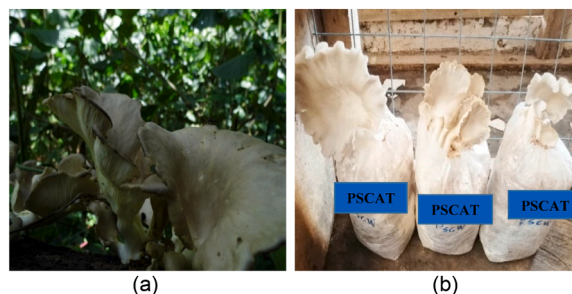


Plate 5. a. *Pleurotus saju-caju* strain PSCAT growing in the wild. b: Flushes of *Pleurotus saju-caju* strain PSCAT fruiting on sawdust after six weeks of incubation.

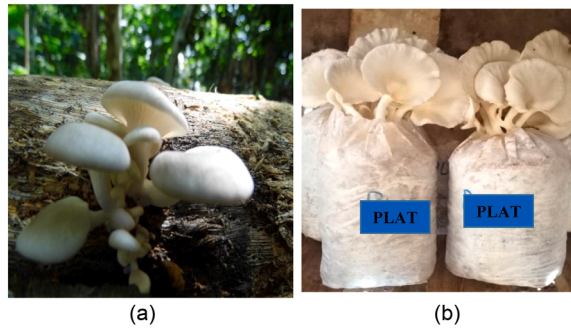


Plate 6. a. *Pleurotus sajju-caju* strain PLAT growing in the wild b: Flushes of *Pleurotus sajju-caju* strain PLAT fruiting on sawdust after six weeks of incubation.

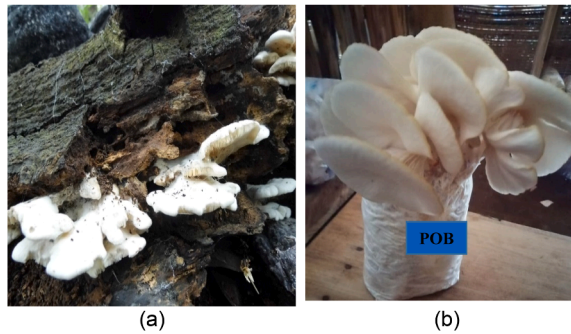


Plate 7. a. *Pleurotus ostreatus* strain POB growing in the wild. b: Flushes of *Pleurotus ostreatus* strain POB Fruiting on sawdust after five weeks of incubation.

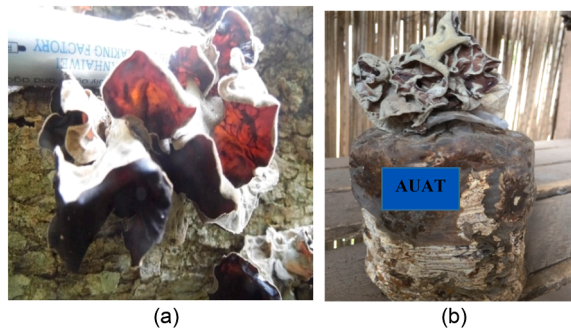


Plate 8. a. *Auricularia auricula* strain AUAT growing in the wild. b: Flushes of *Auricularia auricula* strain AUAT fruiting on sawdust after 4 months of incubation.

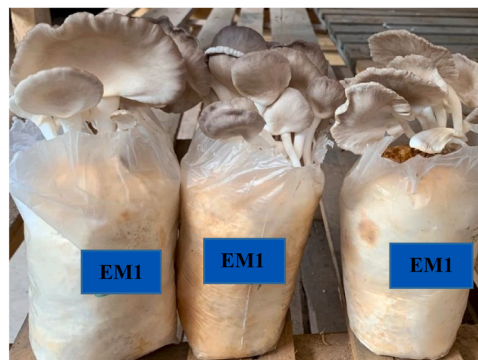


Plate 9. Flushes of *Pleurotus ostreatus* strain EM1 (Commercial strain) fruiting after 6 weeks of incubation.

Table 2
Fruit body yield and biological efficiency of six mushroom strains.

Strain/FB	EM1	POB	PSCAT	PLAT	AUAT	GLB
First Flush (g)	34.7 (6)	95.7 (5)	34.5 (6)	37.5 (6)	15.0 (1)	15.1 (1)
Second Flush (g)	24.2 (4)	92.0 (3)	46.5 (4)	54.5 (4)	NF	15.0 (1)
Third Flush (g)	24.3 (2)	NF	57.8 (3)	9.5 (2)	NF	13.3 (1)
Yield (g)	83.2	187.7	138.8	101.5	15.0	43.4
Biological Efficiency B.E (%)	27.7	62.6	46.3	33.8	5	14.5

Values in brackets () indicate the number of fruitbodies produced by each mushroom strain.

FB: Fruitbodies.

NF: No fruitbody.

whitish. Plates 7a and 7b exhibit flushes of *Pleurotus ostreatus* strain POB growing on sawdust and in the wild respectively. This strain has a very short fruitbody stipe and the edge of the cap turns brownish as it ages. Plates 8a and 8b are flushes of *Auricularia auricula* strain AUAT growing on sawdust and another growing on a tree stump in the wild. Plate 9 is flushes of *Pleurotus ostreatus* strain EM1, which is the main commercially cultivated mushroom in sub-Saharan Africa including Ghana.

There was a wide variation in the biological efficiencies recorded for the different mushroom strains as shown in Table 1. *Pleurotus ostreatus* strain POB, *Pleurotus saju-caju* strain PSCAT and *Pleurotus saju-caju* strain PLAT recorded higher biological efficiencies of 62.6%, 46.3%, and 33.8% respectively. These Biological efficiencies were higher than that of *Pleurotus ostreatus* strain EM1 thus giving the three strains an upper hand over the commercially cultivated *Pleurotus ostreatus* strain EM1. A biological efficiency of 9.73% was observed in studies on *Pleurotus ostreatus* grown on sawdust [30]. Some researchers recorded a similar trend in the reduction of yield per flush [31–33]. This could be due to the use up of nutrients as the mushrooms grow and are harvested. It was also suggested by some authors that there could have been an accumulation of toxic substances within the substrates which could have slowed down the yield after each harvest/flush [29].

Table 2 shows the Fruit body yield and Biological Efficiency of six mushroom strains.. The fruitbody of the first flushes are all higher in numbers than the second and third flushes respectively. This is in line with what has been observed by some authors where they also observed higher numbers of fruitbodies in the first flushes [18,21]. Table 3 on the other hand displays the fruitbody characteristics for the first flushes of all six mushroom strains. *Pleurotus ostreatus* strain POB produced fruitbodies with the biggest cap radius of 10.8 cm, followed by GLB then AUAT and PLAT which both recorded the same values of 8.4 cm for cap size.

As shown in Table 4, *Pleurotus ostreatus* strain POB (wild) contained more moisture (8.82%) than the other strains. This may be due to a lot of water in the environment in which it was found growing. *Pleurotus saju-caju* strain PLAT cultivated recorded the lowest moisture content. These moisture contents are lower than what was recorded by other publications [34]. *Pleurotus ostreatus* (9.6%). *Auricularia auricula* strain AUAT (cultivated) gave the highest ash value (6.70%) while *Ganoderma* sp. strain GLB (cultivated) gave the lowest value (5.12%). The highest fat value (19.88%) was observed in the *Pleurotus ostreatus* strain POB (cultivated) while *Pleurotus saju-caju* strain PSCAT (cultivated) recorded the lowest (12.02%). Other scientists recorded fat values in the range of 0–14% [35]. Lower fat values were observed in *Auricularia auricula-judae*, *Armillariella mellea*, *Agaricus bisporus*, *Pleurotus ferula*, [36] *Pleurotus ostreatus* strain POB (cultivated) could be consumed by weight watchers since its fat content is low.

Table 3
Fruitbody characteristics for the first flushes of six mushroom strains.

Strain	EM1	POB	PSCAT	PLAT	AUAT	GLB
Cap Radius (cm)	5.8	10.8	8.3	8.4	8.4	8.8
Stipe Circumference(cm)	2.4	2.6	3.2	3.1	NA	8.3
Stipe Length (cm)	5.0	8.4	3.3	4.3	NA	8.15

Table 4
Proximate composition and Antinutrient levels of wild and cultivated mushrooms.

Sample	Moisture (%)	Ash (%)	Fat (%)	Protein (%)	Total Carbohydrate (%)	Oxalate (mg/100 g)	Phytate(mg/100 g)
EM1c	3.45 ± 0.06 ^{def}	5.49 ± 0.05 ^{ef}	14.19 ± 0.04 ^e	21.08 ± 0.06 g	55.93 ± 0.07 ^e	30.93 ± 0.29 ^a	98.11 ± 0.56 ^f
PSCATc	2.49 ± 0.17 ^f	6.06 ± 0.34 ^e	12.02 ± 0.13 ^f	21.00 ± 0.18 g	58.85 ± 0.44 ^d	20.92 ± 0.26 ^d	140.16 ± 0.23 ^b
PSCATw	4.71 ± 0.44 ^{cd}	5.17 ± 0.11 ^f	14.92 ± 0.16 ^d	20.57 ± 0.10 ^h	54.83 ± 0.10 ^{ef}	28.45 ± 0.25 ^b	93.32 ± 1.29 g
PLATc	0.90 ± 0.11 g	6.83 ± 0.48 ^d	16.64 ± 0.07 ^b	23.03 ± 0.07 ^e	52.80 ± 0.47 g	11.74 ± 0.28 g	31.60 ± 0.37 ^k
PLATw	4.55 ± 0.45 ^{cde}	7.33 ± 0.07 ^{cd}	14.36 ± 0.07 ^e	22.16 ± 0.11 ^f	52.43 ± 0.14 g	19.52 ± 0.09 ^e	116.97 ± 0.77 ^e
AUATc	4.66 ± 0.43 ^{cd}	16.70 ± 0.15 ^a	16.70 ± 0.18 ^b	33.38 ± 0.17 ^a	28.89 ± 0.42 ^k	26.47 ± 0.28 ^c	149.35 ± 1.55 ^a
AUATw	3.02 ± 0.31 ^{ef}	9.81 ± 0.19 ^b	15.35 ± 0.18 ^{cd}	10.02 ± 0.10 ^k	62.12 ± 0.34 ^e	4.73 ± 0.33 ^k	116.87 ± 0.73 ^e
POBc	7.92 ± 0.24 ^b	7.07 ± 0.10 ^{cd}	19.88 ± 0.37 ^a	27.18 ± 0.08 ^b	38.20 ± 0.45 ^j	7.22 ± 0.12 ^{ij}	62.63 ± 0.58 ⁱ
POBw	8.82 ± 0.63 ^{ab}	7.07 ± 0.10 ^{cd}	15.02 ± 0.10 ^d	23.66 ± 0.13 ^d	45.84 ± 0.66 ⁱ	9.34 ± 0.17 ^h	48.66 ± 1.16 ^j
GLBc	5.32 ± 0.10 ^c	5.12 ± 0.12 ^f	15.00 ± 0.22 ^d	10.35 ± 0.12 ^{jk}	64.22 ± 0.15 ^{ab}	6.37 ± 0.12 ^j	97.69 ± 0.75 ^f
GLBw	5.60 ± 0.94 ^c	7.68 ± 0.11 ^c	15.82 ± 0.11 ^c	17.19 ± 0.10 ⁱ	53.72 ± 0.74 ^{fg}	13.01 ± 0.10 ^f	77.62 ± 0.23 ^h

Data expressed as mean ± Standard deviation. Means that do not share a letter are significantly different at $p < 0.05$.

c-cultivated mushrooms, w- mushrooms collected in the wild.

Pleurotus ostreatus strain EM1 (cultivated) recorded the highest oxalate value (30.93 mg/100 g) while *Auricularia auricula* strain AUAT (wild) recorded the least value of 4.73 mg/100 g. Oyster mushrooms are moderately high in oxalates, and 90% of them are soluble [37]. White button mushrooms and Shiitake mushrooms on the other hand are both very high in oxalates, but 99% of them are insoluble [36]. *Auricularia auricula* strain AUAT (cultivated) exhibited the highest phytate value of 149.35 mg/100 g while *Pleurotus saju-caju* strain PLAT (cultivated) recorded the least phytate value of 31.60 mg/100 g. Dietary phytate has also been assumed to have beneficial properties such as antioxidative and anticarcinogenic effects [38] *Ganoderma* sp. strain GLB (cultivated) showed the highest carbohydrate content of 64.22% and the lowest recorded by *Auricularia auricula* strain AUAT (cultivated). *Auricularia auricula* strain AUAT (cultivated) gave the highest protein value (33.38% ± 0.17) and this falls within the range of 18.32 - 64.70% recorded by earlier work [39]. This could be used to substitute for meat in vegetarian diets and people looking at reducing their meat intake. The position of awareness of mushrooms and mushroom-like networks in West African countries is very scanty for tropical countries this is overall less than 10% of the projected current diversity documented. Within the tropical regions, there exist abundant and huge regions with little or no report on the occurrence of mushrooms [40].

Nine unknown samples and 36 known samples were collected from the Atewa forest reserve. Whilst 19 unknown samples and 22 known samples were collected from the Bia Biosphere. The known samples were classified. Classification of the known samples collected from Atewa forest reserve included: Class Agaricomycetes, Class Basidiomycetes, Class Sordariomycetes and Class Pezizomycetes.

Atewa and Bia forest reserves house a wide diversity of mushrooms. These forests should be protected to conserve the rare wild mushrooms. The proximate composition and presence of antioxidants in *Pleurotus ostreatus* strain POB, *Pleurotus saju-caju* strain PSCAT and *Pleurotus* strain PLAT make them all good substitutions for cases where *Pleurotus ostreatus* strain EM1 strain is unavailable. Farmers will have the option of growing different *Pleurotus* strains thus expanding their choices. The main limitation encountered in the study was the fact that the volume of samples collected per strain was very small.

Conclusion and recommendation

This study shows that Ghanaian forests are home to numerous species of wild mushrooms found growing on various substrates in the wild. Collection, identification and preservation of the mushrooms as well as their germplasm is necessary to conserve them from extinction and future studies. Edible mushrooms are a delicacy in Ghana and their availability is limited due to information on how or whether they are cultivable or can be domesticated. Atewa and Bia Forest reserves harboured a rich collection of wild edible and medicinal mushrooms. *Pleurotus ostreatus* strain EM1 is the only commercially cultivated mushroom species in most West African countries with Ghana, not an exception. *Pleurotus saju-caju* strain PSCAT, *Pleurotus ostreatus* strain POB and *Pleurotus saju-caju* strain PLAT which are all domesticated from the forests of study can be cultivated commercially especially because they are all tropical strains and exhibited several characteristics that are comparable or better to the commercial strain. They may complement *Pleurotus ostreatus* strain EM1 which is a Mauritius strain and the only *Pleurotus* strain actively commercially produced in the sub-region. It is recommended that the shelf life study of these mushrooms are carried out to better understand how to preserve them.

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CRedit authorship contribution statement

Matilda Dzomeku: Conceptualization, Visualization, Writing – original draft, Writing – review & editing. **Francis Alemawor:** Writing – review & editing. **Jacob K. Agbenorhevi:** Writing – review & editing. **ibok N. Oduro:** Writing – review & editing. **Mary Obodai:** Writing – review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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