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Health Promoting Effects of Bioactive Compounds in Mushrooms

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ABSTRACT
Mushrooms are known to be pharmacologically active; hence, they are important in food and medicine. The bioactive compounds present have been reported to exhibit pharmacological activities. During growth, mushrooms acquire various compounds from the substrates, and can also synthesize valuable secondary metabolites that are adjudged to be safe. The nutritional composition of mushrooms is of benefit to human health, coupled with the secondary metabolites synthesized. The nutritional and health potentials of mushrooms have made them a suitable raw material for producing new drugs and functional foods that could be of benefit to mankind. Hence, mushrooms and their products are of immense value in nutraceutical, cosmeceutical, and pharmaceutical industries. This review examines bioactive compounds present in some mushrooms and their benefits to humans.

KEYWORDS
Mushrooms, bioactive compounds, health, benefits

INTRODUCTION
Man has made use of mushrooms as food and medicine from time immemorial. Their use as food is based on their protein and mineral contents[1]. Various evidence-based research has established the pharmacological potential of mushrooms[2-4]. The pharmacological properties of these mushrooms have been associated with the presence of dietary fibres, polysaccharides, terpenes, and other yet to be identified bioactive substances[2,5,6].

These groups of compounds help the body to fight infection and diseases and are called biological response modifiers (BRM). Human needs these compounds to complement insufficient one produced by the body in order to maintain good health. The fruit bodies and the mycelium of mushrooms are rich in these compounds that can positively modulate the body[7,8]. Lentinan isolated from *Lentinus edodes* is a good example of a mushroom bioactive that can strengthen the immune system[9].

Reports have shown that only 10% of the mushrooms on earth are known[10]. However, most of these mushrooms are still in the wild. Presently, there are few or no records of their identities, nutraceutical properties, and bioactives in these wild mushrooms. Earlier studies also revealed that macrofungi such as *Lenzites*, *Coriolopsis*, *Trametes*, *Ganoderma*, *Termitomyces*, and *Pleurotus* species collected from Nigeria

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possess antioxidant, antimicrobial, antiinflammatory, and anticancer properties[11]. Preliminary molecular identification of sequences obtained from some macrofungi collected in Nigeria shows that they are not 100% homologous with similar macrofungi collected from other parts of the world[12-14]. The implication of the genetic difference(s) is that mushrooms collected from different parts of the world contain different bioactive compounds that can be used to solve some health challenges we face as humans. This review aims to highlight the health-promoting properties of bioactive compounds found in mushrooms and their potential therapeutic applications.

MUSHROOMS AND THEIR MEDICINAL PROPERTIES

Edible and medicinal mushrooms are known worldwide to possess several health-promoting properties. In most cases, information on ethnomedicinal uses is not documented but orally passed across from one generation to another[15]. Oso[16] reported that local mushroom merchants and the elderly are the reservoirs of the ethnomedicinal uses of mushrooms in Nigeria. The possibility of losing this useful information is very high. For instance, in Nigeria, various researchers have documented the local use of mushrooms in medicine[15,17].

Mushrooms are known to be a source of natural antibiotics[18]. There have been several reports on the antimicrobial property of several mushrooms such as *Lycoperdon pusilum*, *Pleurotus tuberregium*, *Pleurotus ostreatus*, *Ganoderma lucidum*, *Coriolopsis* species, *Rigidoporus ulmarius*, *Rigidoporus microporus*, *Trametes* spp., *Trametes elegans*, *Trametes lactinea*, and *Lenzites quercina* sourced from Nigeria[19-25]. The cholesterol-lowering ability of mushrooms in rats had been reported. In a study, a diet compounded with mushrooms was found to significantly lower ($p<0.05$) bad cholesterol in rats[26]. Mohammed *et al.*[27] also reported the potential of aqueous extract of *Ganoderma lucidum* to lower blood sugar in rats.

There have been several reports on the antioxidant properties of mushrooms collected in Nigeria. The following mushrooms, *Coriolopsis polyzona*, *Lenzites* species, *Trametes* species, and *Pleurotus* species have been reported to possess significant antioxidant effect[4,11,28-32]. Multimechanistic antioxidant assays revealed that these mushrooms possess good antioxidant properties, and their activities are concentration-dependent. The anticancer, anti-inflammatory, and ability to reduce metal toxicity of some mushrooms have been documented[3,33,34].

BIOACTIVE COMPOUNDS PRESENT IN MUSHROOMS

Mushrooms produce various secondary metabolites[35], and these compounds are good candidates for the development of novel biopharmaceutical agents[36]. These natural compounds are known to have minimal side effects and are inexpensive. Researchers in Nigeria have screened some mushrooms and their extracts qualitatively and quantitatively for mycochemical compounds. It has been reported that the major mycochemicals in mushrooms are polyphenols, alkaloids, oxalate, flavonoids, tannins, and saponins. Quantitatively, the amount of these mycochemicals varies from one species of mushroom to the other. In a study, Ogbomida *et al.*[34] reported the qualitative and quantitative (in percentage) mycochemicals in *Pleurotus tuberregium* as follows: Polyphenols (2.58%), alkaloid (2.46%), oxalate (4.25%), flavonoid (1.68%), tannin (0.38%), and Saponin (trace). Falade *et al.*[37] also reported these mycochemicals in the extract of a nonedible mushroom, *Rigidoporus microcopus*. Table 1 shows the qualitative mycochemical compositions of some mushrooms collected in Nigeria.

The above mycochemicals have been reported to have various effects on animal physiology. For instance, alkaloids are stimulants that act by prolonging the action of several hormones. Flavonoids possess anticancer and antimicrobial effects, while tannins and saponins are known to be effective antifungal, anticancer, and generally as anti-infective agent[38,39]. The taste and aroma of these mushrooms is also affected by these mycochemicals.

Table 1: Mycochemical composition of some mushrooms collected in Nigeria

Mushrooms	Tanin	Saponin	Flavonoids	Steroids	Terpenoids	Alkaloids	Phlobatanin	Anthroquinone	Cg	References
Rigidoporus microporus	+ve	+ve	+ve	+ve	-ve	-ve	-ve	-ve	+ve	Falade *et al.*[37]
Rigidoporus ulmarius	+ve	+ve	+ve	+ve	+ve	+ve/-ve	-ve	-ve	+ve	Ogidi and Oyetayo[24]
Lenzites quercina	+ve	+ve	+ve	+ve	+ve	+ve/-ve	-ve	+ve/-ve	+ve	Ogidi and Oyetayo[31]
Trametes lactinea	+ve	+ve	+ve	+ve	+ve	-ve	-ve	-ve	+ve	Awala and Oyetayo[29]
Trametes elegans	+ve	+ve	+ve	+ve	+ve	+ve	-ve	-ve	+ve	Awala and Oyetayo[30]
Ganoderma lucidium	+ve	+ve	+ve	+ve	+ve	+ve	+ve/-ve	+ve/-ve	+ve	Ogidi and Oyetayo[24]
Pleurotus ostreatus	+ve	+ve	+ve	ND	+ve	+ve	ND	ND	ND	Fasoranti *et al.*[25]

-ve: Absent, +ve: Present, -ve/-ve: Present in some extracts of the mushroom, Cg: Cardiac glycosides and ND: Not Determined

The presence of the following functional groups, viz, hydroxyl (OH), alkyl (CH_3), alkene ($-CH_2$), alkane (-CH), aromatic (CH), amide (NH), carbonyl (C=O), and carboxylic (COOH) has been reported in *Coriolopsis polyzona* and *Lenzites querzina* as revealed by FT-IR spectroscopic analysis[24,33]. These functional groups have also been reported in *Agaricus placomyces*, *A. pseudopratensis*, *Grifola frondosa*[40]. They are the major constituents of polysaccharides, fatty acids, amino acids, sugars, alcohols, terpenoids, phenols, ligands, and flavonoids found in mushrooms[41]. Secondary metabolites containing these functional groups are potentially useful mycochemicals that exhibit antimicrobial, antioxidant, anticancer, and anti-inflammatory properties[42,43].

The bioactive compounds present in mushrooms that have been found to possess bioactivity are polysaccharides, proteins, terpenes, phenolic compounds, and unsaturated fatty acids[44]. Polysaccharides and polyphenols isolated from eight genera of wild mushrooms collected from two locations in Lagos, Nigeria, were reported to have significant anti-cancer properties[45]. These compounds had earlier been reported to have inhibitory effects against yeast cell proliferation in a dose-dependent manner[46].

Mycopolysaccharides possess good immunoceutical properties. Lentinan, a polysaccharide obtained from *Lentinus edodes*, was found to possess good immunoceutical properties, which are effective against viral hepatitis and diseases associated with low immunity[9]. According to Wasser and Weis[6] mushroom polysaccharides act as anticancer by activating different immune responses in the host. An earlier report on the potential anticancer properties of mushrooms collected in Nigeria was demonstrated by Adewusi *et al.*[47]. Two common edible mushrooms, *Termitomyces robustus* and *T. striatus*, indigenous, were reported to possess anticancer properties. Furthermore, the anticancer effects of three wild macrofungi, collected in Nigeria were had been reported by Unekwu *et al.*[11]. The extracts from these wild macrofungi were able to inhibit the proliferation of several human cancer cell lines.

Mushrooms collected in Nigeria are also rich in healthy fatty acids and their derivatives Table 2. Adeoye-Isijola *et al.*[48] reported the presence of 9,12-Octadecanoic acid ethyl ester (37.39%) and Hexadecanoic acid ethyl ester (14.49%) as the two most occurring bioactive compounds in the ethanolic extract of *Lentinus squarrosulus* Mont. In another study, Mensah-Agyei *et al.*[49] reported that four compounds were dominant in acetone extract of *Daedalea elegans* accounting for 83.58% [9,12-octadecadienoic acid (44.64%), n-hexadecanoic acid (23.59%), 9(11)-dehydroergosteryl benzoate (8.37%), octadecanoic acid (6.98%)] Ogidi *et al.*[33] had earlier reported the presence of these groups of fatty acids in extracts obtained from *Lenzites quercina*. Most of these bioactive compounds are used in the formulation of cosmetics, pharmaceuticals, and nutraceuticals[50,51]. Generally, GC-MS analysis of extracts revealed the presence of fatty acids. Proteins and peptides in mushrooms are also very important. About 19 to 35% dry weight of mushrooms is made up of protein. They possess health-enhancing properties such as enhancement of the digestion and absorption of exogenous nutritional ingredients, the modulation of the immune function to help the host in the defense against invasion by pathogens, and the inhibition of some enzymes[52]. Lectins, fungal immunomodulatory proteins (FIPs), ribosome inactivating proteins (RIPs), ribonucleases, and laccases are examples of proteins and peptides with health-promoting promoting-properties[44].

Table 2: GC-MS profiling of acetone extract of *Daedalea elegans*

Peak number	R. Time	Name	Area (%)
1	7.154	Benzoic acid	0.40
2	8.449	Nonanoic acid	0.14
3	8.734	Oxetane, 2,2,4-trimethyl-	0.28
4	9.714	n-Decanoic acid	0.09
5	12.551	Phthalimide	0.44
6	12.720	Dodecanoic acid	0.24
7	14.057	E-2-Hexenyl benzoate	0.21
8	14.267	2,4-Difluorobenzene, 1-benzyloxy-	0.16
9	15.067	Tetratetracontane	0.55
10	15.141	Iso Propylphosphonic acid, fluoroanhydride	0.28
11	15.453	Benzene, (1-methylundecyl)-	0.21
12	15.628	Tetradecanoic acid	0.76
13	15.868	Cyclohexanepropanol, .alpha.,2,2,6-tetramethyl	0.56
14	16.464	Pentadecanoic acid	0.71
15	16.703	E-2-Hexenyl benzoate	0.32
16	16.845	Pentadecanoic acid	0.97
17	17.435	1-Decanol, 2-hexyl-	0.46
18	17.764	9-Tetradecenal, (Z)-	1.67
19	18.045	n-Hexadecanoic acid	23.59
20	18.837	Phthalic acid, butyl undecyl ester	1.08
21	18.972	Eicosanoic acid	0.79
22	19.801	9,12-Octadecadienoic acid (Z,Z)-	44.64
23	19.970	Octadecanoic acid	6.98
24	23.641	Bis(2-ethylhexyl) phthalate	2.64
25	24.302	2,2,4-Trimethyl-3-(3,8,12,16-tetramethyl-he	1.95
26	26.423	9(11)-Dehydroergosteryl Benzoate	8.37
27	26.694	9(11)-Dehydroergosterol Tosylate	1.28
28	26.948	4,6-Decadienal,8-ethyl-10-[4-hydroxy-8-(2	0.22
			100.00

Source: Mensah-Agyei *et al.*[49]

Other bioactive compounds found in abundance in mushrooms are the terpenes. They are volatile, unsaturated hydrocarbons. They are among the largest classes of secondary metabolites produced by fungi and plants. They are made up of five carbon isoprene units, which can be arranged in thousands of ways. This made them structurally diverse. Terpenoids are a modified class of terpenes with different functional groups and an oxidized methyl group moved or removed at various positions[53]. Terpenoids are biologically active and are known to possess a wide range of health benefits such as antioxidant, antiviral, anticancer, anti-inflammatory, antimalarial, and anticholinesterase activities[44]. Terpenoids have therefore found application in the field of foods, drugs, cosmetics, hormones, vitamins, and so on[53]. They are classified into monoterpenoids, sesquiterpenoids, diterpenoids, sesterpenoids, and triterpenoids (Fig.1-5) depending on the number of carbon units they possess[53,54].

Mushrooms can absorb mineral elements and bioaccumulate them as functional organic compounds. Some of these essential elements are selenium, iron, zinc, and so on. For instance, selenium is required for the biosynthesis of selenoenzymes and selenoproteins, which are important in normal physiological processes. Maximum uptake of selenium plays a prominent role in preventing various types of cancer and diseases like diabetes, age-related immunosuppression, and even problems related to fertility[55]. Iron, on its own, is essentially involved in the synthesis of adenine triphosphate (ATP), transport of oxygen, Deoxyribonucleic Acid (DNA), and electron transport[56]. It is also a component of hemoglobin and myoglobin, and when it is low in supply, it leads to a deficiency disease called iron deficiency anemia (IDA). In a study, *Pleurotus* spp., enriched with selenium was found to significantly enhance the antioxidant and antimicrobial properties than non-selenium fortified *Pleurotus* spp.[57].

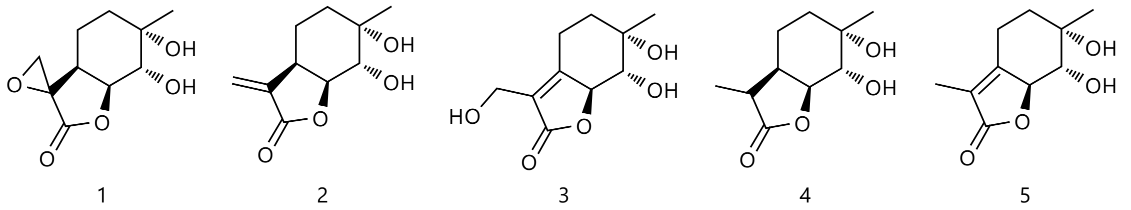

Fig. 1: Chemical structure of five (1-5) monoterpenes isolated from *Pleurotus cornucopiae*[54]

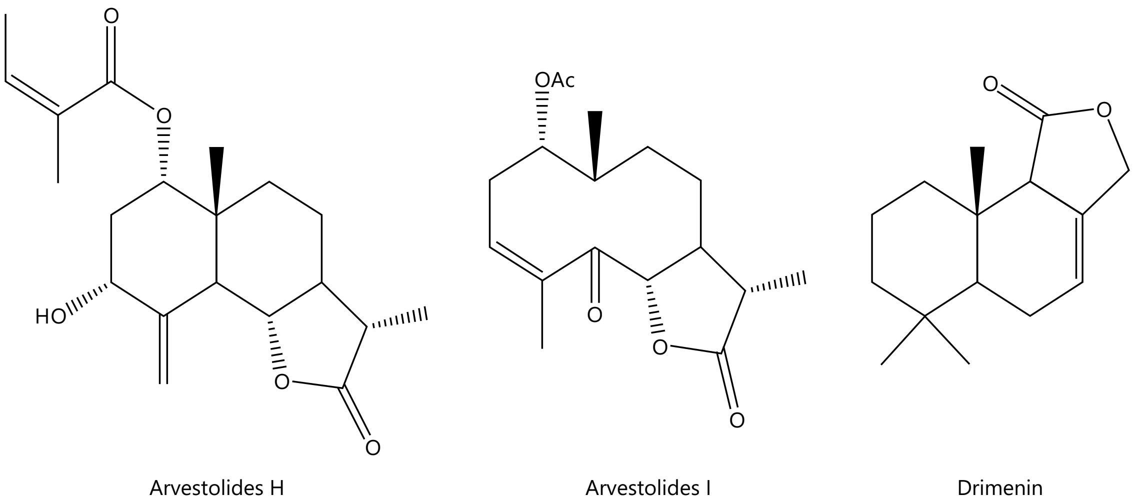

Fig. 2: Structures of sesquiterpenoids isolated from mushrooms[53]

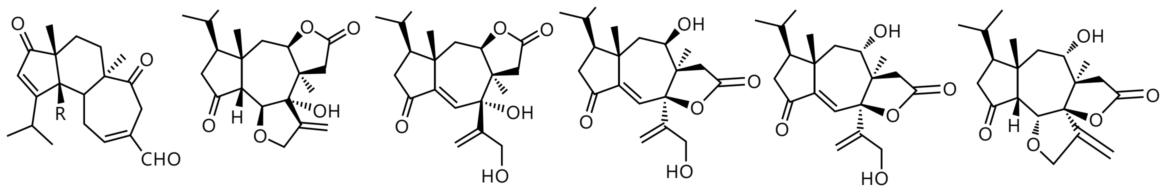

Fig. 3: Structures of five (5) diterpenoids isolated from mushrooms[54]

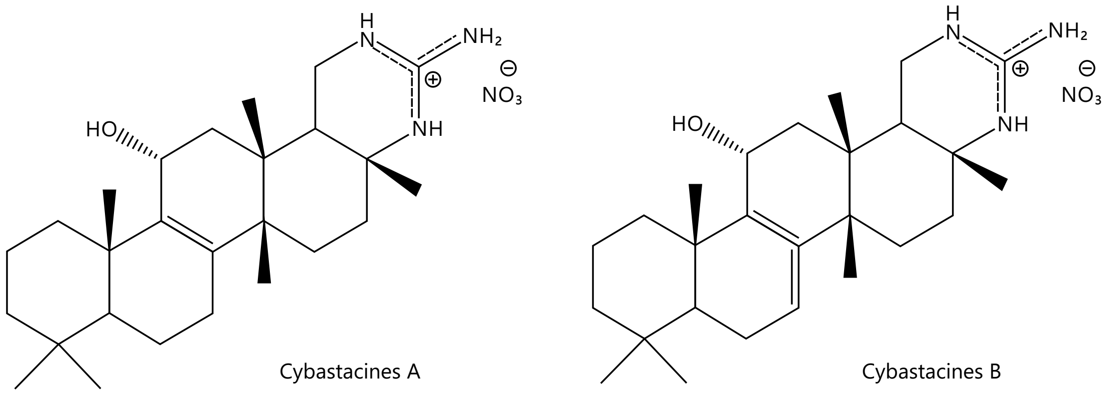

Fig. 4: Structures of two Sesterpenes (Cybastacines A and Cybastacines B)[53]

Mushrooms can therefore be used as a vehicle to supply mineral elements that are not in an adequate amount in our diet. This will be a definite strategy to solve the problem of mineral elements malnutrition. Therefore, artificial cultivation of mushrooms on rationally prepared growth medium rich in mineral elements may help to produce novel bioactive compounds that can help in solving the present problem of ineffectiveness of currently known synthetic pharmaceutical compounds.

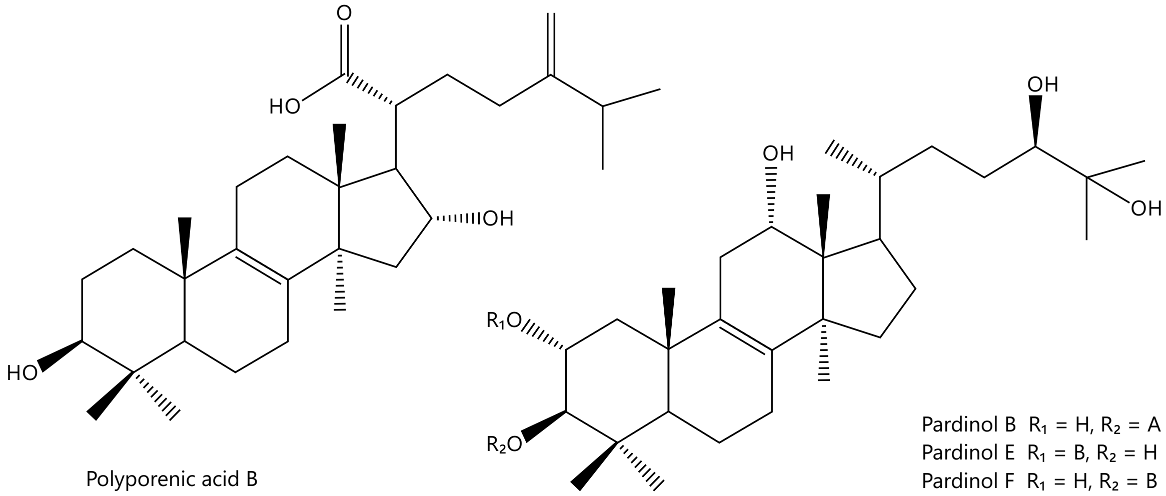

Fig. 5: Structures of triterpenes[53]

CONCLUSION

Currently, mushrooms in Nigeria are mainly underutilized as food, while their pharmacological potential has not been well exploited. The two major constraints militating against the sustainable exploitation of mushrooms are the seasonal nature of mushrooms and the difficulty in distinguishing edible from poisonous species. Practical steps can be employed in solving the problem of the seasonal nature of mushrooms, while a combination of morphological and molecular procedures can be used to solve the problem of identification. Moreover, aggressive enlightenment on their health-promoting properties has to be made known to both the poor and rich in Nigeria. Presently, a lot of people in Nigeria may be looking at mushrooms as a poor man's food.

SIGNIFICANCE STATEMENT

This study discovered the immense potential of mushrooms as natural sources of bioactive compounds that can be beneficial for the development of affordable, safe, and effective products in the nutraceutical, cosmeceutical, and pharmaceutical industries. These compounds include polysaccharides, phenolics, terpenoids, and proteins, which exhibit antioxidant, antimicrobial, anti-inflammatory, and anticancer activities. The study also highlights the socioeconomic implications of mushroom bioactives, particularly in their capacity to generate employment through bioindustry development. This study will help researchers to uncover the critical areas of mushroom biotechnology and industrial applications that many researchers were not able to explore. Thus, a new theory on the sustainable utilization of fungal bioresources for global health and economic development may be arrived at.

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