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Review

An appraisal of the metabolites, pharmacological and biotechnological significance of edible mushrooms

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Mushrooms are universally valued for their dietary and therapeutic significance. Their importance could be attributed to numerous nutritive and dietary substances including polysaccharides, terpenoids, phenolics and other light molecular bioactive compounds. These compounds offer optimal health benefits and have been identified as a potential source of nutritional and medicinal products against several debilitating and food-related disorders. Here, we present an updated synopsis of the medicinal attributes of mushrooms, while also highlighting the technological advancements in their cultivation that have led to the birth of engineered species with improved traits that could alleviate malnourishment and contribute towards food security, offer health benefits, and provide efficient ways of waste management.

Keywords: edible fungi; food security; mushroom; nutraceutical; waste management

INTRODUCTION

Fungi are achlorophyllous eukaryotic organisms with peculiar characteristics that distinguish them from organisms in other kingdoms (Vinceti *et al.*, 2013). One feature that places fungi in a different kingdom is the composition of their cell wall. The cell wall is composed of chitin while that of plants and bacteria is made up of cellulose and peptidoglycan, respectively (Vinceti *et al.*, 2013). Fungi can be unicellular (yeasts) or multicellular (moulds and mushrooms). Like animals, fungi are heterotrophs (chemoorganotrophs) and derive their carbon from organic sources. Growth is their means of movement, except for their reproductive units (spores), which may be dispersed or disseminated by animate agents, such as insects and animals, or inanimate agents like air and water (Vinceti *et al.*, 2013).

In an ecological system, fungi are the major scavengers and decomposers. These characteristics place fungi in a group of organisms called *Eumycota* (Eumycetes or true fungi), with same ancestor (i.e., monophyletic group). This fungal group is functionally and physically different from the myxomycota (slime moulds) and oomycetes (water moulds). Genetically, fungi share common characteristics with animals than plants. Although, fungi are abundant worldwide, they are mostly inconspicuous due to their small size. However, they

may be more conspicuous, either as moulds or as mushrooms during fruiting (Chang, 2006). The fruiting arrangements of a certain species of mushrooms have psychotropic complexes and are used recreationally or traditionally in spiritual rites (Chang, 2006).

Fungi play vital roles in the breakdown of organic matter, which facilitates nutrient cycling and exchange in the environment. Generally, their roles in human food supplies and the overall economies are significant (Chang, 2006). For instance, fungi serve as leavening agents in dough making, are useful in the fermentation of alcoholic beverages and wine and are a source of food in the form of mushrooms (Bilal *et al.*, 2010). However, some species produce mycotoxins, such as alkaloids and polyketides, that are poisonous to biological systems, while others are important pathogens of animals and humans (Bilal *et al.*, 2010). Many crops are also lost due to fungal attack, such as rice blast, early and late blight of potatoes, wilting of tomato, etc. (Chang, 2006).

Although, knowledge on the biodiversity of kingdom Fungi remains scanty (Chang, 2006), advancements in molecular genetics have revealed the importance of DNA investigation to be unified into a catalogue to complement the present historical grouping system based on cytology, morphology, and biochemical traits (Vinceti *et al.*, 2013). Nevertheless, the

general classification of fungi is based largely on their spores' characteristics and spore-bearing structures (Vinceti *et al.*, 2013).

Among the various groups of fungi, mushrooms are fleshly with edible fruiting bodies which are sometimes termed macrofungi (Bi *et al.*, 1993). For macrofungi to be edible, it must be free from poisonous effects and have desirable taste and aroma (Bilal *et al.*, 2010). Species of mushrooms, such as *Macrolepiota*, *Plerutous*, *Auricularia*, *Armillaria*, *Pholiota*, and *Coprinus* are predominantly found in native forests (Fekadu, 2014). Edible fungi nourish the human body, helps in proper growth and development and are occasionally consumed for their perceived medicinal purposes (Bilal *et al.*, 2010).

Mushrooms are either harvested wild or cultivated, and are readily obtainable for use, while the few species difficult to grow can be engineered. More than 3000 mushrooms are fit for consumption, but only about 3.3% of total edible species are cultivated in large quantity and are readily available for sales (Khatun *et al.* 2012). Processes, such as fermentation and anti-nutrient factors processing, may render certain poisonous mushrooms fit for consumption. Identification must be carefully done before considering any mushroom from the wild edible. Careful and accurate identification of a species is the only safe way to ascertain edibility, and the only way against possible accidents. As it happens to consumable items, mushrooms that are suitable for consumption for some persons can cause adverse reactions to certain individuals (Chang, 2006). Therefore, necessary precautions should be observed before mushrooms are consumed.

According to Chang (2006), some species of the *Amanita* genus, such as the *Amanita phalloides*, are deadly toadstools that are frequently confused with mushrooms that are fit for consumption and are responsible for many fatal poisonings. Table 1 presents the features critical for the identification of common edible fungi.

Although, attempts have been previously made on reviewing different aspects of edible fungi (Cheung, 2013; Olawale

and Muhammed, 2013; Singh, 2017; Ganesan and Xu, 2018; Ukwuru *et al.*, 2018; Jabłońska-Ryś *et al.*, 2019), no comprehensive report exists on its pharmacological and biotechnological applications. Hence, the present review appraised the bioactive metabolites, scope, and significance of mushrooms as therapeutic and biotechnological agents to date. It is envisaged that this paper will provide useful insights into the significance of mushrooms and could inspire further studies on the benefits of these achlorophyllous eukaryotic species.

MATERIAL AND METHODS

Relevant information was gathered online using scientific literature repertoires, such as PubMed, ScienceDirect, Scopus, Google Scholar etc. using phrases/and words like edible fungi, metabolites of edible fungi, structures, uses, toxicological profiles of edible fungi, pharmacological significance and medicinal uses, limitations of use etc. The data gathered were used to conceptualise a framework (Figure 1) highlighting both the inclusion and exclusion criteria deemed necessary for the topic under review (Moher *et al.*, 2009).

RESULTS AND DISCUSSION

Mushroom

Mushroom is a macrofungal organism with a characteristic fruiting body, which can either be above or below the ground and conspicuous (Chang and Miles, 1982). Mushrooms have been widely taken as foods and nutritional supplements (Chamberlain *et al.*, 1998), and very often they are delicious with beneficial organoleptic properties (Vinceti *et al.*, 2013).

Mushrooms fit into two classes (basidiomycetes and ascomycetes). The basidiomycetes are the club fungi while the ascomycetes are popularly called sac fungi, and have their sexual spores situated in the basidium and ascus, respectively (Vinceti *et al.*, 2013). The life cycle of mushrooms involves anamorphic and teleomorphic stages which are asexual and sexual reproductive phases, respectively. The

Table 1. Common mushrooms and their characteristics identification features.

Mushroom	Habitat	Gills	Cap color	Cap shape	Average cap size (cm)	Stem color	Stem shape	Average stem size (cm)
<i>Chanterelles</i> spp.	Soil	widely spaced	Brown	Flat	5	Brown	tapering	12
<i>Flammulina velutipes</i>	Dead wood	closely spaced	Reddish to brownish	Convex	1.5-2	Cream	tapering	10
<i>Lentinus squarrosulus</i>	Dead wood	Crowded	White	kidney shape	5–7	White	tapering	5
<i>Pleurotus populinus</i>	Dead wood	Crowded	White	flat or kidney shape	6.5-7	White	short	1-1.5
<i>Pleurotus pulmonarius</i>	Dead wood	widely spaced	White	Flat	2-2.5	White	short	1
<i>Psathyrella delineaata</i>	Dead wood	closely spaced	Reddish to brownish	Conical	1	White	tapering	4
<i>Termitomyces microcarpus</i>	Soil	widely spaced	White	Flat	1	White	tapering	4
<i>Termitomyces robusta</i>	Soil	Crowded	brown	Flat	10	Cream	tapering	8
<i>Volvariella volvacea</i>	Dead wood	closely spaced	grayish brown	Conical	3–6	whitish to brownish	club shape	2–5

absence of a photosynthetic feature in mushrooms is responsible for their inability to manufacture food. Thus, they, like other heterotrophs, depend on autotrophs for food and absorb nutrients from their substrates. Mushrooms have a stem-like structure called stipe which keeps the pileus in an aerial position. Pictorial representations of some edible and medicinal mushrooms are shown in Figures 2 and 3, respectively.

Nutritional composition of edible fungi

Although poisonous fungi exist, there are many edible ones, and of these are those that possess arrays of nutritional compounds, such as sugars, proteins and minerals, lectins, ergotamine, proteases etc. (Guillamón *et al.*, 2010; Wani *et al.*, 2010).

Carbohydrate content

The content of carbohydrates in mushrooms accounts for 50–65% of weight while sugars specifically account for 11%. For instance, *Coprinus atramentarius* contains 24%

carbohydrates. The mushroom sugar (mannitol) which is dominant, account for almost 80% of the sugars (Florezak *et al.*, 2004). A study also confirmed that a garden-fresh mushroom contains about 0.9% mushroom sugar, 0.59% glycogen, 0.28% reducing sugar, and 0.91% hemicellulose (Wannet *et al.*, 2000).

Protein content

Dry matter of mushrooms contains protein, and its concentration is dependent on the size of pileus, composition of substrates, time of gathering and type of species (Bilal *et al.*, 2010). The protein content of the mushrooms varies from flush to flush. It ranged from 32 to 42% in *A. bisporus* mycelium on the dry weight basis. Generally, mushrooms are more proteinous than vegetables and wild plants. In fact, it has been previously reported that mushrooms have all the essential amino acids necessary for human growth and development (Anon, 2007).

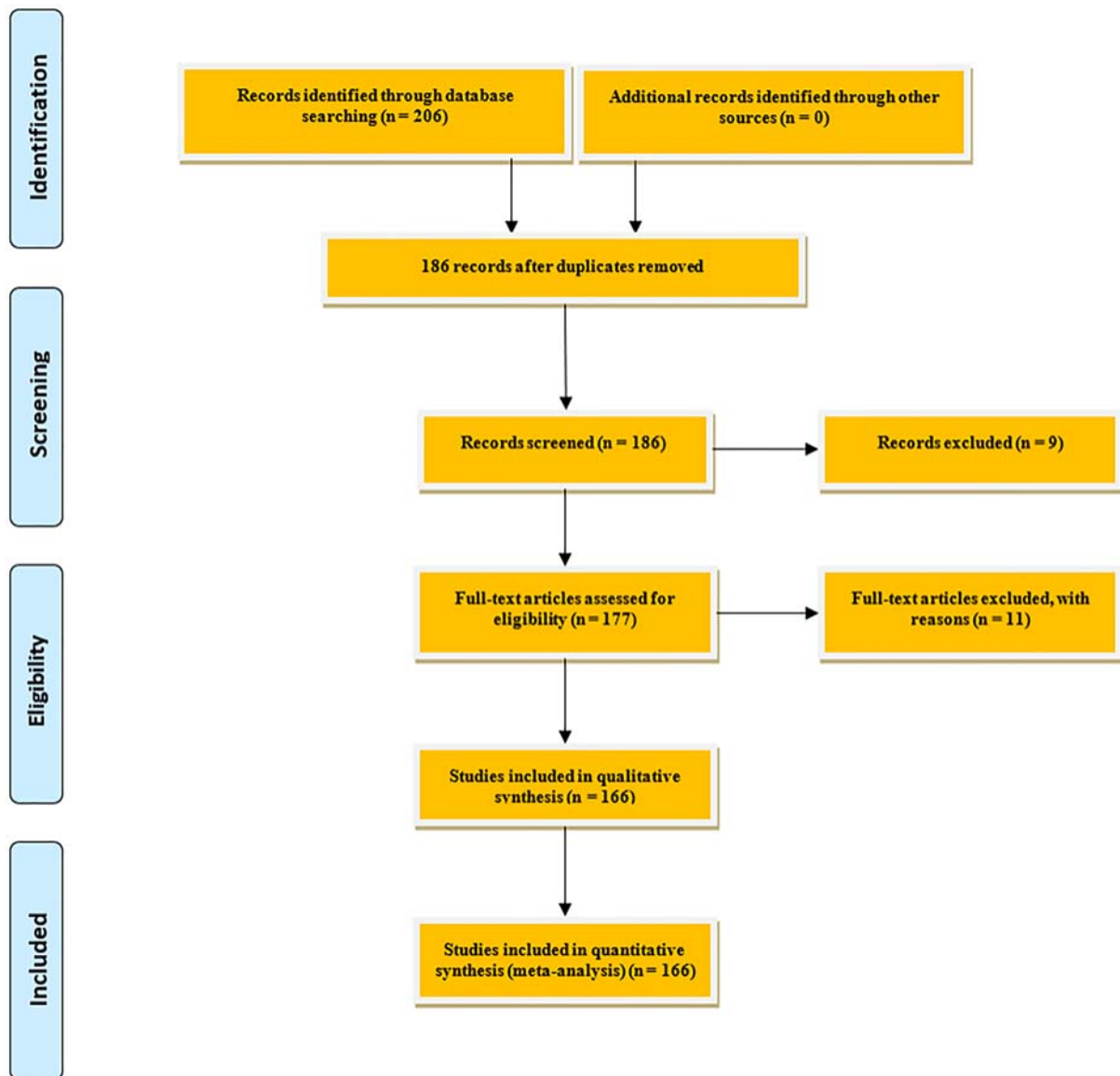


Figure 1. PRISMA flow chart showing the numbers of identified, screened, included, and excluded studies for the review.



Figure 2. Pictorial representation of some edible mushrooms. TR, TL and TM are mushrooms in the genus *Termitomyces*. Although, they are considered one of the best edible mushrooms in the world, attempts at cultivation by humans have been abortive to date and are only cultivated by termites. They are mostly grown and collected by humans in the wild (Stamets, 2000; Boa, 2004). FV is a well-known mushroom in East Asia and can be easily cultivated using spawn, it is a popular ingredient for Asian cuisine. The wild forms differ in colour and texture (Bao *et al.*, 2009). LS has potential to be used as food, functional food and nutraceuticals and is easily cultivated all over the world (Mhd Omar *et al.*, 2015). PP, PO and Pp are gilled mushroom are a group of most cultivated edible mushrooms in the world and they have also been used in mycoremediation of pollutants (Cohen *et al.*, 2002). VV is mushroom fit for consumption and cultivated throughout East and Southwest Asia and used widely in Asian cuisines (Chang and Miles, 1982). CS are among the most popular wild edible mushrooms in the world. They grow in clusters in forests and are difficult to cultivate through mycelium due to their symbiotic relationship with the root of higher plants, mycorrhizal (Arora and Dunham, 2008). PD grows saprophytically on dead wood (Frank *et al.*, 2010), RV usually grows in the wild (Phillips *et al.*, 2006).

Amino acids composition

The 20 common amino acids that makeup proteins vary in amount and are quantitatively different. There are nine essential amino acids (lysine, methionine, tryptophan, threonine, valine, leucine, isoleucine, histidine, and phenylalanine) that are not synthesised *de novo* within the body. Generally, mushrooms have the whole nine essential amino acids that are important to human health (Oyetayo *et al.*, 2007). Lysine is the most abundant essential amino acid in mushrooms while tryptophan and methionine seem to have the least occurrence (Chan, 1981).

Fat content

The fat constituent in mushrooms is not as high as those found in other classes of food. Unsaturated fatty acids are mostly present in the fruiting bodies of mushroom (Yilmaz *et al.*, 2006; Sinanoglou *et al.*, 2014; Sande *et al.*, 2019) and species-dependent. For instance, the fat content of *Suillus granulatus*, *S. luteus*, and *A. campestris* is 2.04%, 3.66% and 2.32%, respectively (Yilmaz *et al.*, 2006). Generally, mushrooms contain linolenic acid which is a good source of fats (Yilmaz *et al.*, 2006).

Vitamins and minerals

Mushrooms are rich in vitamins especially vitamin D2 (Taofiq *et al.*, 2017). Wild mushrooms are richer in vitamin D2 than *Agaricus bisporus* (Urbain *et al.*, 2016). Mushrooms have vitamins B-complex and C in little quantities, but not rich in vitamins A, D, and E (Heleno *et al.*, 2010). They contain a high-level of mineral element including the major (Cu, Zn, Fe, Mo, Cd) and minor minerals (Ca, K, P, Na, Mg) that are vital for human growth and development. Importantly, their mineral composition is dependent on several factors, such as the kind of species, stage of development, the length of the fruiting body, and the nature of the substrates for cultivation. An edible wild mushroom contains more mineral content than the cultivated ones (Rudawska and Leski, 2005). Table 2 reveals the mineral and vitamin C contents of some commonly consumed mushrooms, while the comprehensive proximate analysis of selected mushrooms is presented in Table 3.

Metabolites and pharmacological significance of mushrooms

Mushrooms play important roles in human health and have been nutritionally, medicinally and therapeutically valued (Chang and Miles, 2004). Their fruiting bodies and

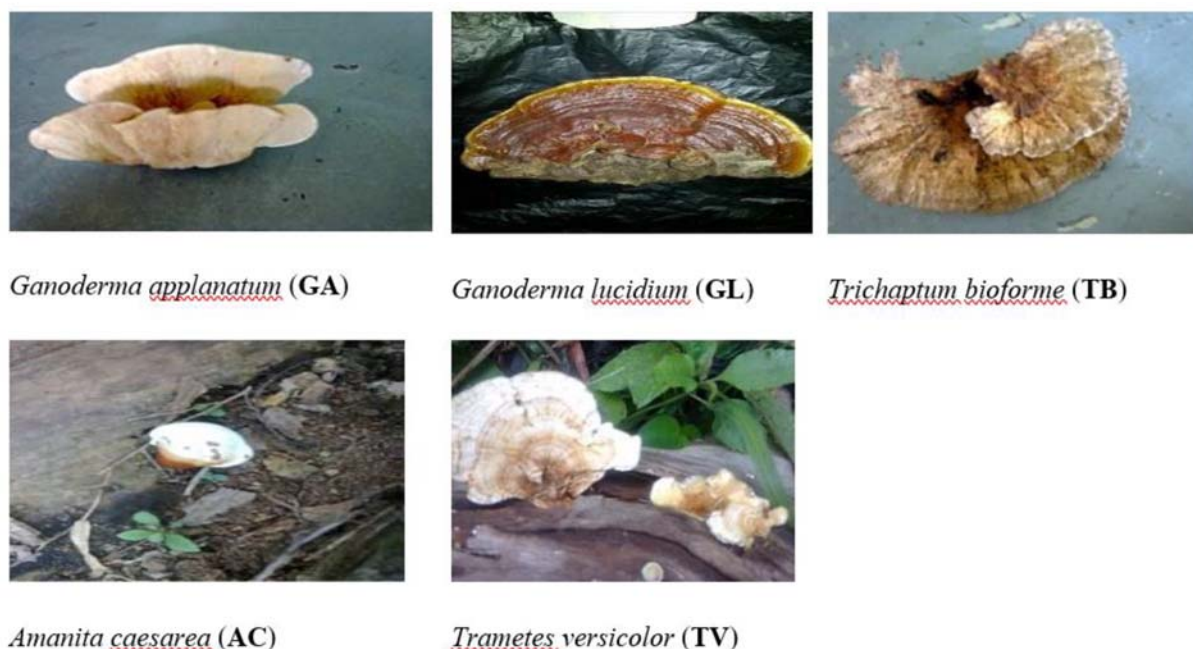


Figure 3. Pictorial representation of some medicinal mushrooms. GA grows as a mycelium on the wood of living and dead trees, and widely distributed. It is common at the base of hardwood while GL is effectively cultivated on hardwood or sawdust, the wild form is extremely rare and edible (Smith *et al.*, 2000). AC is highly medicinal and edible, though can easily be confused with poisonous mushroom. It grows in the wild (Smith *et al.*, 2000). TB is grown on dead hardwood stumps and logs and it is not edible. TV is normally used in traditional medicine to boost immune system, it grows in the wild and it is edible (Jakovlev, 2011).

Table 2. Minerals and vitamin C composition of some selected edible mushrooms.

Mushroom	Ca (mg/ 100 g)	Na (mg/ 100 g)	K (mg/ 100 g)	Mg (mg/ 100 g)	Vitamin C (unit)
<i>Pleurotus ostreatus</i>	87.50	6.52	2.68	51.27	10.16
<i>Termitomyces robusta</i>	54.10	3.92	4.56	32.42	10.25
<i>Volvariella volvacea</i>	37.15	1.58	2.62	25.22	6.57
<i>Termitomyces microcarpus</i>	38.45	2.67	4.34	40.75	12.15
<i>Pleurotus pulmonarius</i>	40.25	3.59	7.25	20.75	14.10

Adapted from Rudawska and Leski (2005).

membranes are usually rich in phenolics and proteoglycans (Guillamón *et al.*, 2010; Wani *et al.*, 2010). Diverse groups of metabolites including peptides, polyketides, alkaloids, terpenoids, flavonoids, carotenoids, etc. have also been found in mushrooms (Khatun *et al.*, 2012; Xu and Beelman, 2015). These compounds have been reported as pharmacological agents against several life-threatening diseases, such as cancer, viral infections, inflammation, diabetes, cardiac failure, neurodegenerative disorders, etc. (Chen *et al.*, 2006, Ajith and Janardhanan, 2007; Rathee *et al.*, 2012; Zambonelli, 2012), their amount and effectiveness vary across species, and normally dependent on stage of development, substrate, fruiting environments, storage settings and preparation techniques (Guillamón *et al.*, 2010; Wani *et al.*, 2010).

Antitumor activity

As cancer remains one of the leading causes of mortality worldwide, the need for alternative or complementary antitumor agents to replace or complement non-target specific and

Table 3. Proximate composition of selected mushrooms.

Mushroom	Moisture (%)	Ash (%)	Crude protein (%)	Crude fibre (%)	Crude Fat (%)	Carbohydrate (%)
<i>Pleurotus ostreatus</i>	7.12	5.65	32.31	5.97	15.38	33.57
<i>P. pulmonarius</i>	10.99	7.95	23.63	8.16	11.63	37.64
<i>Termitomyces microcarpus</i>	9.69	24.19	38.14	5.92	13.81	8.27
<i>T. robusta</i>	11.40	13.71	41.19	5.27	9.07	19.36
<i>Volvariella volvacea</i>	12.36	16.10	42.63	5.14	10.60	13.17

Adapted from Adejumo *et al.* (2015).

host-toxic conventional remedies are important (Lavi *et al.*, 2009; Lin *et al.*, 2010; Patel and Goyal, 2012). Mushrooms are a good antitumor candidate due to their plethora anticancer bioactive constituents, such as calcaelin, krestin, lectin, lentinan, polysaccharides, hispolon and psilocybin (Singh *et al.*, 2010; Patel and Goyal, 2012). While the polysaccharide-Krestin (PSK) from *Coriolus versicolour* has been approved as adjuvant for gastric cancer therapy (Tsukagoshi, 1984), lentinan from *Lentinus edodes* is an established anticancer therapy in several countries including Japan (Ina *et al.*, 2013). Also, marmorin, a ribosome-inactivating protein (RIP), was isolated from *Hypsizygus marmoreus* and showed antitumor activity (Wang and Ng, 2005; Wong *et al.*, 2008). Xylose-specific lectin from the fresh fruiting bodies of *Xylaria hypoxylon* has also been shown to possess significant antimitogenic and antitumor activities (Liu *et al.*, 2006). According to Zhang *et al.* (2009), lectins (lectin- 32 kDa) from *Pholiota adiposa*, *Hericium erinaceum*, and *Russula lepida* have potentials as antitumor agents. Similarly, calvacin, a moderately heat-stable, non-diffusible basic mucoprotein from *Calvatia gigantea* was isolated and demonstrated as an effective antitumor agent (Chatterjee *et al.*, 2011). Generally, the anticancer bioactive components of edible mushrooms have been demonstrated via the stimulation of apoptosis enhancement, host defense system, and cytotoxic effects against endothelial cells as well as inhibition of topoisomerase, mitotic kinase, cysteine protease, and angiogenesis (Chen *et al.*, 1993; Ng, 1998; Brzin *et al.*, 2000).

Hypoglycemic activity

The low-fat content, high dietary fibre, and protein content of edible mushrooms make them appropriate nutrient for the prevention and treatment of hyperglycemia (Alarcon-Aguilara *et al.*, 1998). In an early work by Ahmad *et al.* (1984), lectin components of *Agaricus campestris* and *A. bisporus* were found to improve insulin level of experimental rats. Lavi *et al.* (2011) reported that ganoderan A and B glucans of *Ganoderma lucidum* fruiting bodies showed significant hypoglycemic effects. Other bioactive compounds such as ganoderan, coriolan, dehydrotrametenolic acid, and γ -aminobutyric acid (GABA) found in *Ganoderma lucidum*, *Trametes versicolour*, *Laricifomes officinalis*, and *Boletus edulis* were also reported to possess hypoglycemic properties (Gao *et al.* 2002; Rathee *et al.* 2012).

Antioxidant activity

The mycelium and fruiting bodies of various edible mushrooms contain antioxidant molecules, such as phenolic compounds, tocopherols, carotenoids, and flavonoids (Bai *et al.*, 2013). These compounds counteract and prevent oxidative insults caused by free radicals, such as superoxide anion, hydroxyl radical, and hydrogen peroxide (Côté *et al.*, 2010; Sánchez, 2017). For instance, phenolic analogues isolated from *Hericium erinaceus* (Mizuno, 1999) as well as catechin and other flavonoids from *Lentinus squarrosulus*, *L. polychrous*, and *L. edodes*, *P. ostreatus*, *Hypsizygus tessellatus* exhibited significant antioxidant activity (Attarat and Phermthai, 2015; Chowdhury *et al.*, 2015). Similarly, Dai *et al.* (2010) reported a positive correlation between the phenolic content (hispidin) from *Phellinus* spp. and its antioxidant property, which is an indication that mushroom is a natural antioxidant. Generally, the fruiting bodies of many edible mushrooms such as *Agaricus arvensis*, *A. bisporus*,

A. silvaticus, *A. silvaticus*, *A. romagnesii* (Barros *et al.*, 2007, 2008), *Boletus badius*, *B. edulis*, *Cantharellus cibarius* and *C. cornucopioides* (Palacios *et al.*, 2011), *Clitocybe alexandri* (Vaz *et al.*, 2010), *Ganoderma lucidum*, *Lactarius piperatus*, *Lactarius deliciosus* and *Lentinula edodes* (Yang *et al.*, 2002; Cheung and Cheung, 2005; Kim *et al.*, 2008) amongst others contain antioxidant molecules. Furthermore, although the mushroom's fruiting body appears to be the component that contains the highest amounts of antioxidants, antioxidant compounds have also been found in the mycelium component of some edible macrofungi, such as *Ganoderma tsugae* (Tseng *et al.*, 2008), *Pleurotus albidus* (Gambato *et al.*, 2016), *Coprinus comatus* (Vamanu, 2013) and *Agaricus blazei* (Carvajal *et al.*, 2012).

Hypocholesterolemic activity

Cholesterol is vital for various body metabolisms, such as hormones and vitamins synthesis; however, excess lipoprotein cholesterol predisposes the body to various diseases, such as cardiovascular diseases, obesity, and diabetes (Stapleton *et al.*, 2010). Conventional anti-hypercholesterolemia drugs used for the prevention and treatment of hypercholesterolemia, such as fibrates, niacin and simvastatin are usually associated with severe side effects such as hepatic impairment, cirrhosis, diarrhea, and peptic ulcer (Ko *et al.*, 2004; Keong *et al.*, 2015). These accompanied host toxicities of conventional anti-hypercholesterolemia agents have left researchers to exploit natural organic sources, such as macrofungi, for hypocholesterolemic agents. An early study by Kaneda and Tokuda (1966) reported the cholesterol-lowering activity of *Auricularia polytricha*, *Agaricus bisporus* and *Lentinus edodes*. In addition, the *in vitro* and *in vivo* anti-hypercholesterolemic properties of members of genus *Pleurotus*, such as *Pleurotus ostreatus* and *P. ferulae*, have been investigated (Berger *et al.*, 2004). More recently, Fombang *et al.* (2016) investigated the cholesterol-lowering activity of aqueous extract of *P. florida*. Their findings demonstrated that extract reduced the total glycerides and cholesterol in rats fed with high cholesterol diets.

Immunomodulatory activity

Medicinal mushrooms are used as immunomodulatory medications particularly in Asian countries. The β -D-glucans are important component of several basidiomycetes and ascomycetes cell wall and can help the human immune system to fight against diseases (Reshetnikov and Tan, 2001; Batbayar *et al.*, 2012; Mizuno and Nishitani, 2013). Specifically, the immunomodulators such as (1 $\rightarrow$ 3)- β -D-glucan with (1 $\rightarrow$ 6)- β -D side chain, (1 $\rightarrow$ 3)- β -D-glucan, and polysaccharide-protein complex have been reported in *Lentinula edodes*, *Ganoderma lucidum*, and *Grifola frondosa* (Chihara *et al.*, 1969; Nanba *et al.*, 1987; Lee *et al.*, 2003; Firenzuoli *et al.*, 2008).

Antimicrobial activity

Due to the inevitable competition for space and nutrients in the environment with other organisms, mushrooms possess plethora antimicrobial arsenal, such as applanoxidic acids, oxalic acids, and epicorazins, to ensure their proliferation and survival in their natural habitat (Rathee *et al.*, 2012). They have abundant deposits of natural antibiotics, antifungal, and antiparasitic agents. Several extracts obtained from mushrooms' mycelia have been recognised to possess remarkable antibacterial and antifungal properties (Eo *et al.*, 1999).

For instance, the total extract of *Ganoderma pfeifferi* has been reported to impede the growth of microorganisms associated with skin diseases (Mothana *et al.*, 2000). Bender *et al.* (2003) also reported the antibacterial activity of oxalic acid synthesised from *Lentinula edodes* (Berk.). Furthermore, mycelial extracts of *L. edodes* showed significant antiparasitic activity against *Paramecium caudatum* (Badalyan, 2004). Similarly, while Chu *et al.* (2005) extracted a peptide (pleurostrin) from *P. ostreatus* and demonstrated its antifungal activity, agrocybin (peptide) isolated from fresh fruiting bodies of *Agrocybe cylindracea* elicited showed antifungal activity against *Mycosphaerella arachidicola*, with an IC₅₀ value of 125 µM at different temperatures up to 80°C (Zhang *et al.*, 2003; Ngai *et al.*, 2005).

Antiviral activity

Viral diseases are quite difficult to treat since they cannot be treated by common drugs (antibiotics) used to treat bacterial infections. Bioactive molecules, such as ganoderic acid B, lucidadiol, ganoderiol F, applanoxidic acids and ganodermadiol, found in mushrooms display enormous antiviral activities. The antiviral mechanisms of these components include, but not limited to, inhibition of viral enzymes and nucleic acids, and enhancement of host immunity to better combat viral infections (Brandt and Piraino, 2000). Bracket mushroom, *Ganoderma lucidum* have been used to manage patients with HIV type 1 (HIV-1) (El-Mekkawy *et al.*, 1998). Wang *et al.* (2007) also isolated and elucidated the antiviral efficacy of a peptide (SU2) from *Russula paludosa*.

Anti-allergic activity

Many macrofungi are immune boosters, while others contain molecules for immune response alleviation. This immune response alleviation property can be of great importance for the management of ever-increasing allergic ailments. Sano *et al.* (2002) reported that various edible basidiomycetes, such as *Pleurotus eryngii*, *Pholiota nameko*, *Hypsizygus marmoratus*, and *Flammulina velutipes*, have anti-allergic properties. In addition, the consumption of *Tricholoma populinum* reverted serious allergic symptoms in a recurring progressive inflammatory and thrombotic patient. From previous studies, hispolon and hispidin, obtained from *Inonotus hispidus*, were used to prevent the chemiluminescence reaction of human mononuclear blood cells (Ali *et al.*, 1996).

Anti-inflammatory activity

The existence of aromatic hydroxylated compounds in edible mushrooms has been identified as one of the agents responsible for their anti-inflammatory properties (Côté *et al.*, 2010; Han *et al.*, 2013; Elsayed *et al.*, 2014). Other bioactive molecules, such as proteoglycan, ganoderic acids A, B, G and H, with anti-inflammatory effects have been isolated from edible fungi (Rathee *et al.*, 2012). The phenolic molecule, pyrogallol, was extracted from *Agaricus bisporus*, *C. cibarius*, and *Lactarius deliciosus* (Witkowska *et al.*, 2011), and was reported to show anti-inflammatory activity. Grifolin and its derivatives are farnesyl phenolic compounds with good anti-inflammatory properties and have been obtained from the edible mushroom *Albatrellus ovinus* (Nukata *et al.*, 2002). Furthermore, the aqueous, ethanolic and methanolic extracts of various edible mushroom (*Pleurotus pulmonarius*, *Ganoderma lucidum* and *G. frondosa*) parts have demonstrated significant anti-inflammatory properties (Zhang *et al.*, 2002). While Kim *et al.* (2003) have elucidated the ethanolic extract and a

purified proteoglycan from *Phellinus linteus* as remarkable anti-inflammatory agents, the polysaccharide constituents of *Termitomyces albuminosus*, *Lentinus polychrous*, *Phellinus linteus* and *Flammulina velutipes* have also been reported as potent anti-inflammatory compounds (Wu *et al.*, 2010; Badalyan, 2014).

A comprehensive list of selected mushrooms of therapeutic significance, the implicated metabolites and their structure is presented in Table 4.

Mushroom and mushroom biotechnology

Mushrooms have been put into good biotechnological use in significant areas of science, such as bioremediation, fortification of foods, enzyme technology, nutraceuticals and pharmaceuticals etc.

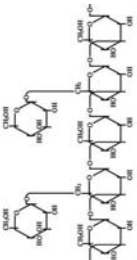
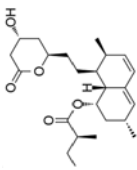
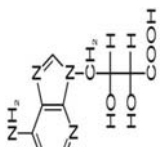
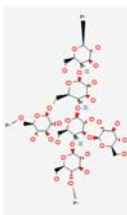
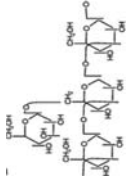
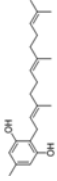
Production technology

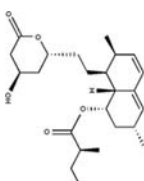
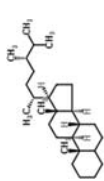
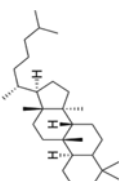
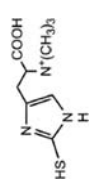
The consumption of mushroom by man is probably as old as human existence. Due to its pleasant flavour and taste, human populations have attempted to domesticate mushroom in latter stage. The earliest cultivated edible fungus was a species of *Auricularia* which was cultivated about 1000 years ago in China. The next species to be cultivated was *Lentinus edodes* (Chang, 2006), and this occurred several years ago (Chang and Miles, 1982). *Agaricus bisporus*, which is leader in the global mushroom industry today in terms of its production, was first cultivated in France in 1650 (Dwyer, 2010). Since then, several other mushrooms have been domesticated. Mushrooms are cultivated on lignocellulosic substrates. Some of the mushrooms can be cultivated in composted (fermented and partially degraded) substrates primarily cereal straws and other supplements, especially the button mushroom (*Agaricus* spp.). Use of composted substrate is mainly aimed at facilitating mycelium development and elimination of microorganisms. However, mushrooms such as *Pleurotus*, *Lentinus*, *Flammulina*, *Auricularia*, *Pholiota*, *Tremella*, *Calocybe*, *Ganoderma*, *Coprinus* etc. can be grown on fresh, lignocellulosic substrates (Yadav, 2004). With technological advancement, new vista in mushroom science has been achieved for the conservation of germplasm, high yielding species with yield stability, longer shelf life and remarkable biological activity (with desirable traits such as quality nutrients, good taste and palatable aroma etc). The application of molecular biology techniques to the genetic improvement programmes has introduced innovative DNA-based markers and provides much needed advancements in genetics and breeding of cultivated mushroom to have genetically improved strains and hybrids (Yadav, 2004).

Enzyme production

Scientists have great interest in the enzymes obtained from mushrooms because of their ability to degrade cellulosic materials. In a study to detect the protein in *L. tuber-regium*, varied important enzymes were identified and these enzymes have found practical application in paper industry and also to treat and enhance digestibility in animals (Chang, 1999; Shashirekha *et al.*, 2005; Manjunathan and Kaviyaran, 2010). Also, certain bioactive proteins in mushrooms, such as ribosome-inactivating proteins (RIPs), fungal immunomodulatory proteins (FIPs), and laccases, have been reported to elicit enzymatic activities (Wang and Ng, 2005; Wong *et al.*, 2008).

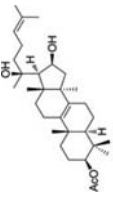
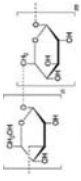
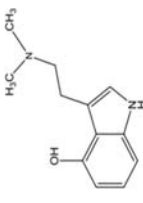
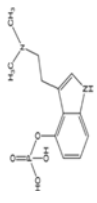
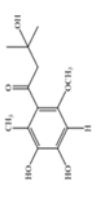
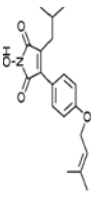
Table 4. Selected examples of edible fungi bioactive metabolites and their therapeutic values.

Metabolite	Type	Structure	Bioactive property	Model	Source	Mechanism of Action/Addendum	Reference
Lentinan	Polysaccharide		Antitumor activity	<i>In vivo</i>	<i>Lentinus edodes</i> (shiitake)	This metabolite has been approved for cancer treatment in several countries including Japan. It activates macrophages and monocytes, and decreases IL-6 and PGE ₂ synthesis.	(Sagar <i>et al.</i> , 2007; Ina <i>et al.</i> , 2013)
Lovastatin (mevinolin)	Polyketide		Inhibitor of cholesterol biosynthesis; anti-inflammatory and antioxidant properties	<i>In vivo, In vitro</i>	<i>Agaricus bisporus</i> ; <i>Agrocybe cylindracea</i> ; <i>Boletus edulis</i> ; <i>Hypsizigus marmoreus</i> ; <i>Pholiota nameko</i> ; <i>Pleurotus</i> spp.	It inhibits cholesterol synthesis via the inhibition of 3-hydroxy-3-methylglutaryl-CoA reductase involved in cholesterol biosynthesis	(Aarons <i>et al.</i> , 2007; Chen <i>et al.</i> , 2012; Lo <i>et al.</i> , 2012)
Eritadenine	Nucleic acid derivative		Cholesterol lowering activity; anti-parasitic activity	<i>In vivo, In vitro</i>	<i>Lentinus edodes</i>	Unlike lovastatin, eritadenine does not inhibit cholesterol synthesis but rather facilitates its removal.	(Chibata <i>et al.</i> , 1969; Enman <i>et al.</i> , 2008; ČTRNÁCTÁ <i>et al.</i> , 2010)
Polysaccharide-Krestin (PSK)	Protein-bound polysaccharide		Antitumor activity; antiviral activity	<i>In vivo, In vitro, clinical studies</i>	<i>Coriolus versicolour</i>	It activates antitumor immune responses via the adjustment of Th1/Th2 imbalance and enhancement of IL-15 production. Approved as adjuvant for gastric cancer therapy.	(Tsukagoshi, 1984; Hirose <i>et al.</i> , 1987)
Polysaccharide-peptide (PSP)	Protein-bound polysaccharide	NA	Immunomodulating and antitumor activities	<i>In vivo</i>	<i>Coriolus versicolour</i>	Exerts antitumor activity via enhancing apoptosis, and stimulating host defense system and cytotoxic effects against endothelial cells	(Chen <i>et al.</i> , 1993; Ng, 1998)
Schizophyllan	polysaccharide		Anticancer activity	<i>In vivo, clinical studies</i>	<i>Schizophyllum commune</i>	Antitumor activity occurs through host-mediated immune responses	(Ren <i>et al.</i> , 2012)
Grifolan	Polysaccharide		Anticancer and antioxidant properties	<i>In vivo, In vitro, clinical studies</i>	<i>Grifola frondosa</i> ; <i>Albatrellus</i> spp.	It inhibits tumour cells growth via inducing ATP depletion and blockage of ROS production	(Mayell, 2001; Konno <i>et al.</i> , 2002; Kodama <i>et al.</i> , 2003; Ye <i>et al.</i> , 2005)

Lanostane	Triterpenoid		Anticancer; Cytotoxic activity	<i>In vitro</i>	<i>Astraeus odoratus</i> ; <i>Ganoderma lucidum</i> ; <i>Naematoloma fasciculare</i>	Exerts antitumor and antiproliferative effects via the induction of apoptosis (Wu <i>et al.</i> , 2013; Phosri <i>et al.</i> , 2014; Srisurichan <i>et al.</i> , 2017)
Lectin	Protein	NA	Antitumor, anti-HIV, hypotensive and immunomodulatory activities	<i>In vivo, In vitro</i>	<i>Agrocybe</i> spp.; <i>Boletopsis leucomelas</i> ; <i>Clitocybe nebularis</i> ; <i>Hericiium erinaceum</i> ; <i>Pleurocybella</i> spp.; <i>Volvariella volvacea</i> <i>Clitocybe nebularis</i>	Exerts antitumor effect via apoptosis induction (Koyama <i>et al.</i> , 2002; Suzuki <i>et al.</i> , 2009; Li <i>et al.</i> , 2010; Singh <i>et al.</i> , 2014)
Clitocypin	Protein	NA	Anticancer property	<i>In vitro</i>		Exerts anticancer activity via the inhibition of cysteine protease development (Brzin <i>et al.</i> , 2000)
Ergostane	Triterpenoid		Anticholinergic, antioxidant, cytotoxic and anti-inflammatory activities	<i>In vivo, In vitro</i>	<i>Antrodia cinnamomea</i> ; <i>Antrodia salmonea</i> ; <i>Taiwanofungus camphoratus</i>	Exerts anticancer effect via the suppression of metastasis and angiogenesis, induction of apoptosis and autophagy, cell cycle arrest, enhancement of immune response, and regulation of oxidative stress. (Wu <i>et al.</i> , 2010)
Cucurbitane	Triterpenoid		Antitumor, anti-HIV, and cytotoxic properties	<i>In vivo, In vitro</i>	<i>Russula rosacea</i> ; <i>Russula lepida</i>	Exerts effect via the neutralization of chemical carcinogens, including ROS and NO donors. Some cucurbitane triterpenoids have also been isolated from poisonous mushrooms such as <i>Hebeloma vinosophyllum</i> and <i>Leucopaxillus gentianeus</i> , thus care must be taken when considering mushroom for consumption. (Wang <i>et al.</i> , 1994; Jian-Wen <i>et al.</i> , 2002)
Ergothioneine	Thiol compound		Antioxidant, cytoprotective and anti-inflammatory properties	<i>In vivo, In vitro</i>	<i>Agrocybe cylindracea</i> ; <i>Antrodia camphorata</i> ; <i>Cordyceps</i> spp.; <i>Grifola frondosa</i> ; <i>Pleurotus</i> spp.	Neutralizes hydroxyl, peroxy and peroxynitrate radicals. Ergothioneine is found throughout the human body (Franzoni <i>et al.</i> , 2006; Dubost <i>et al.</i> , 2007; Chen <i>et al.</i> , 2012; Lo <i>et al.</i> , 2012)
γ -aminobutyric acid (GABA)	Free amino acid		Anti-diabetic and hypotensive activities	<i>In vivo, In vitro</i>	<i>Agaricus blazei</i> ; <i>Agrocybe cylindracea</i> ; <i>Antrodia</i> spp.; <i>Boletus edulis</i> ; <i>Cordyceps</i> spp.; <i>Flammulina velutipes</i> ;	– (Chen <i>et al.</i> , 2012; Dhakal <i>et al.</i> , 2012)

(Continued)

Table 4. Continued.

Metabolite	Type	Structure	Bioactive property	Model	Source	Mechanism of Action/Addendum	Reference
Astraeusin (a type of lanostane)	Triterpenoid		Antimalarial and antimicrobial activities	<i>In vitro</i>	<i>Astraeus asiaticus</i> ; <i>Astraeus odoratus</i>	It exhibits antimalarial activity against <i>Plasmodium falciparum</i>	(Isaka et al., 2016; Isaka et al., 2017)
Tremellan	Polysaccharide	NA	Immunoenhancement and proposed antiviral property	<i>In vivo, In vitro</i>	<i>Tremella fuciformis</i>	Also exhibits antitumor activity	(Ren et al., 2012; Zhang et al., 2017)
Pleuran	Polysaccharide		Anti-dermatitis and hypoglycemic activities	<i>In vivo, clinical studies</i>	<i>Pleurotus</i> spp.	Exhibits antioxidant, anti-inflammatory, regenerative, immunomodulatory, radioprotective, and moisturising effects	(Ren et al., 2012; Jesenak et al., 2015)
Ganoderan	Polysaccharide	NA	Treatment and prevention of cerebral arteriosclerosis	<i>In vivo, In vitro</i>	<i>Ganoderma lucidum</i>	Inhibition of NADPH oxidising enzyme expression	(Feng et al., 2014)
Psilocin	Alkaloid		Antioxidant property	<i>In vitro</i>	<i>Psilocybe cubensis</i>	It also induces psychoactive effects such as relief of depression, ease of anxiety and alteration of mood	(Kovacic et al., 2015; Lenz et al., 2017)
Psilocybin	Alkaloid		Exhibits pharmacological action against depression	Clinical studies	<i>Psilocybe</i> spp.	After treatment with psilocybin, changes in resting-state brain blood flow and functional connectivity were observed in treatment-resistant depression	(Carhart-Harris et al., 2017)
Antrolone	Benzoid compound		Anti-inflammatory property	<i>In vitro</i>	<i>Antrodia cinnamomea</i>	Exerts anti-inflammatory effect via decreasing nitric oxide, PGE ₂ , and pro-inflammatory cytokines production	(Carhart-Harris et al., 2017; Yen et al., 2018; Ganesan et al., 2019)
Antrodin C	Maleimide derivative		Antioxidant, anti-diabetic, antitumor	<i>In vitro</i>	<i>Antrodia cinnamomea</i>	Exerts anti-tumor effect via the suppression of Smad2/3 and β -Catenin Signaling Pathways	(Kumar et al., 2015; Senthil et al., 2017; Ganesan et al., 2019)
Ganopoly	Polysaccharide	NA	Hepatoprotective	Clinical studies	<i>G. lucidum</i>	Normalization of aminotransferase and clearance of hepatitis B surface antigen	(Gao et al., 2002)

NA: Structure not available.

Protoplast technologies

The usefulness of the protoplast technology in several areas of mushroom biology has been well established. The major area of interest has focused on its application as a tool for genetic manipulation. Protoplast technology is a non-conventional method of genetic manipulation and plays important role in cultivation and nurturing of mushrooms. Gene transfer using protoplast has been technologically advanced to prevent hindrance of orthodox breeding systems on the genes. The development of a gene transfer system in edible fungi has been deemed useful in genetic recombination and strain improvement (Yoo and Cha, 1993). In the Basidiomycetes, the most exciting aspect of this endeavour concerns the generation of novel interspecies hybrids. It is important to note that strain improvement by protoplast fusion has been performed in closely related species. Successful recombination between distantly related species provides the opportunity for a broadening of the gene pool. The uptake of isolated cell organelles by protoplasts may allow the exploitation of the protoplast fusion technique on a more refined level. DNA-mediated transformation related to gene vectors has enhanced knowledge of molecular biology of higher fungi. Development of this method also opens many possibilities for the commercial production of medically important substances found in mushrooms (Yoo and Cha, 1993). Protoplast technology provides a highly feasible technique for interspecific and intergeneric hybridisation among the economically important mushrooms. Hybridisation using protoplast fusion is mostly used for breeding between intraspecific incompatible basidiomycetes species, development of multifunction such as the formation of physiologically active substances, aromatic and growth acceleration of mycorrhizal mushrooms and genetic analysis (Ogawa, 1993).

Lignocellulose biodegradation with mushroom

The most recycled biological compounds available in the planet are the lignocelluloses which comprises cellulose, hemicellulose and lignin. These lignocelluloses are produced through photosynthesis and allied biological processes (Singh and Gautam, 2004). Significant development in science and technology has led to a quantum jump in the agricultural commodities production. This in turn has further accelerated the lignocellulosic biomass accumulation. Major parts of these are burnt giving rise to complex hazards including oxygen deficient environment, respiratory diseases and poor vision. Biodegradation of different varieties of lignocellulosic waste through mushroom cultivation is important as it results in the formation of simpler eco-friendly compounds and protein-rich food of therapeutic importance (Singh, 2000). For instance, the basidiomycete and ascomycete mushrooms degrade and grow on lignocellulosic substrates using laccases (Wang and Ng, 2005; Wong *et al.*, 2008). The degradation provides them with useful nutrients necessary for their growth.

Bioremediation

Bioremediation is the process of using microorganisms to decrease or eradicate threats in the environment, these threats or dangers are normally the buildup of deadly chemicals and other dangerous material wastes. It can also be the use of organic procedures to treat pollutants. Most investigations in bioremediation have been on bacteria, but lately, bioremediation using fungi (myco-remediation) is becoming interesting and calling for the attention of researchers and

ecologists around the globe. *Pleurotus* spp. are commonly used because they have the useful enzymatic scheme which reduces contaminants successfully and proficiently. *Phanerochaete*, *Trametes*, *Bjerrandera* and *Pleurotus* have been noticed to have the ability to degrade pollutants. While they do not use lignin as energy source, they employ carbon or cellulose-containing substances as their energy source (Singh *et al.*, 2008). Thus, corncobs, straw, sawdust can be used to grow and improve the ability of these fungi to degrade pollutants at the polluted sites. The major technique used by these fungi is the ability to produce enzymes that can degrade lignin. These enzymes that can degrade lignin are known as extracellular lignin modifying enzymes (LMEs) and they are not specific to a particular substrate which enables them to be able to degrade several toxic, harmful contaminants which have similar structure with lignin. Myco-remediation involves the use of mushrooms to turn these pollutants into non-toxic harmless substances. Mushrooms have been shown to accumulate radionuclide metals and even rare earth elements. They are also potentially useful in detecting the presence of deleterious compounds (Kalač, 2001).

CONCLUSION AND PERSPECTIVES

Mushrooms can make significant influence on the incomes of indigenous residents through food provision. Their cultivation signifies a valued low-scale enterprise opportunity, and this has been well advocated by FAO as one of the ways to enhance food security in developing nations (Marshall and Nair, 2009). Besides this benefit, mushroom cultivation is mainly dependent on recycling of agricultural wastes which are abundantly available globally. For instance, the global areas with rice-wheat cropping system currently faced with the challenge of mounting crop residues could harness the residues for utilisation in mushroom production in a manner that could ensure effective management of these agrowastes. Efforts could also be intensified to exploit the commercial utilisation of mushroom substrate left after cultivation for preparation of organic manure, vermicompost, briquettes, etc. that could be additional source of income and contribute towards improved economy. Mushrooms are functional foods and are a source of biologically valuable compounds that offer great therapeutic potential for the prevention and management of several diseases. While the potential therapeutic importance of mushrooms is enormous, the detailed mechanisms involved in eliciting most of these pharmacological activities remain elusive and require evidence-based insights. Hence, studies and clinical trials need to be carried out with a view to lend scientific credence to their attributes in offering health benefits, taking advantage of their bioactive compounds. While technological advancement has led to the birth of engineered mushrooms (such as *Lentinula edodes*, *Coprinus cinereus*, *Flammulina velutipes* etc.) with inherent attributes that alleviate food-related challenges (e.g., malnourishment), offer health benefits, and provide efficient ways of managing energy supply, it is still evident that mushroom cultivation holds promising grounds for today's pharmaceutical industry owing to the plethora of useful pharmacological compounds. Their applications in tackling malnutrition and as a vital tool for repair, renewal and remediation of the exploited ecosystem is an illustration of a low cost, feasible and versatile technology to achieve the universal rising quest for good food and eco-friendly environment.

Conflicts of Interest

The authors declare no conflict of interest.

References

- AARONS, C.B., COHEN, P.A., GOWER, A., REED, K.L., LEEMAN, S.E., STUCCHI, A.F. & BECKER, J.M. 2007. Statins (HMG-CoA reductase inhibitors) decrease postoperative adhesions by increasing peritoneal fibrinolytic activity. *Annals of Surgery* 245: 176–184.
- ADEJUMO, T., COKER, M. & AKINMOLADUN, V. 2015. Identification and evaluation of nutritional status of some edible and medicinal mushrooms in Akoko Area, Ondo State, Nigeria. *International Journal of Current Microbiology and Applied Sciences* 4: 1011–1028.
- AHMAD, N., KHAN, M.M., RASTOGI, A.K. & KIDWAL, J.R. 1984. Effect of age on *Agaricus bisporus* PHA-B stimulated insulin release and $^{45}\text{Ca}^{2+}$ uptake *in vitro* by islets of langerhans. *Acta Diabetologica Latina* 21: 349–355.
- AJITH, T.A. & JANARDHANAN, K.K. 2007. Indian medicinal mushrooms as a source of antioxidant and antitumor agents. *Journal of Clinical Biochemistry and Nutrition* 40: 157–162.
- ALARCON-AGUILERA, F.J., ROMAN-RAMOS, R., PEREZ-GUTIERREZ, S., AGUILERA-CONTRERAS, A., CONTRERAS-WEBER, C.C. & FLORES-SANEZ, J.L. 1998. Study of the antihyperglycemic effect of plants used as antidiabetics. *Journal of Ethnopharmacology* 61: 101–110.
- ALI, N.A., PILGRIM, H., LUDKE, J. & LINDEQUIST, U. 1996. Inhibition of chemiluminescence response of human mononuclear cells and suppression of mitogen induced proliferation of spleen lymphocytes of mice by hispolon and hispidin. *Pharmazie* 51: 667–670.
- ANON A. 2007. Mushrooms may be active against fowl parasite. Thisday 11, 36.
- ARORA, D. & DUNHAM, S.M. 2008. A new, commercially valuable chanterelle species, *Cantharellus californicus* sp. nov., associated with live oak in California, USA. *Economic Botany* 62: 376–391. doi:10.1007/s12231-008-9042-7.
- ATTARAT, J. & PHERMTHAI, T. 2015. Bioactive compounds in three edible *Lentinus* mushrooms. *Walailak J Sci Technol* 12: 491–504.
- BADALYAN, S.M. 2004. Antiprotazoal activity and mitogenic effect of mycelium of culinary-medicinal Shiitake mushroom *Lentinus edodes* (Berk.) Singer (Agaricomycetideae). *International Journal of Medicinal Mushrooms* 6: 131–138.
- BADALYAN, S.M. 2014. Potential of mushroom bioactive molecules to develop healthcare biotech products, In: 8th International Conference on Mushroom Biology and Mushroom Products.
- BAI, M.S., WANG, C., ZONG, S.C., LEI, M. & GAO, J.M. 2013. Antioxidant polyketide phenolic metabolites from the edible mushroom *Cortinarius purpurascens*. *Food Chemistry* 141: 3424–3427.
- BAO, H.N.D., USHIO, H. & OHSHIMA, T. 2009. Antioxidative activities of mushroom (*Flammulina velutipes*) extract added to Bigeye Tuna meat: Dose-dependent efficacy and comparison with other biological antioxidants. *Journal of Food Science* 74: C162–C169.
- BARROS, L., BAPTISTA, P., CORREIA, D., CASAL, S., OLIVEIRA, B. & FERREIRA, I. 2007. Fatty acid and sugar compositions, and nutritional value of five wild edible mushrooms from Northeast Portugal. *Food Chemistry* 105: 140–145.
- BARROS, L., FALCÃO, S., BAPTISTA, P., FREIRE, C., VILAS-BOAS, M. & FERREIRA, I.C.F.R. 2008. Antioxidant activity of *Agaricus* sp. mushrooms by chemical, biochemical and electrochemical assays. *Food Chemistry* 111: 61–66.
- BATBAYAR, S., LEE, D.-H. & KIM, H.-W. 2012. Immunomodulation of fungal β -glucan in host defense signaling by dectin-1. *Biomolecules and Therapeutics* 20: 433–445.
- BENDER, S., DUMITRACHE, C.N., BACKHAUS, J., CHRISTIE, G., CROSS, R.F., LONERGAN, G.T. & BAKER, W.L. 2003. A case for caution in assessing the antibiotic activity of extracts of culinary-medicinal Shiitake mushroom [*Lentinus edodes* (Berk.) Singer] (Agaricomycetideae). *International Journal of Medicinal Mushrooms* 5: 31–36.
- BERGER, A., REIN, D., KRATKY, E., MONNARD, I., HAJJAJ, H., MEIRIM, I., PIGUET-WELSCH, C., HAUSER, J., MACE, K. & NIEDERBERGER, P. 2004. Cholesterol-lowering properties of *Ganoderma lucidum* *in vitro*, *ex vivo*, and in hamsters and minipigs. *Lipids in Health and Disease* 3: 2.
- BI, Z., ZHENG, G. & TAIHUI, L. 1993. *The Macrofungus Flora of China's Guangdong Province*. Hong Kong, Chinese University Press.
- BOA, E.R. 2004. *Wild Edible Fungi: A Global Overview of Their Use and Importance to People*. Rome, Food and Agriculture Organization of the United Nations.
- BRANDT, C.R. & PIRAINO, F. 2000. Mushroom antivirals. *Recent Research Development in Antimicrobial Agents Chemotherapy* 4: 11–26.
- BRZIN, J., ROGELJ, B., POPOVIĆ, T., ŠTRUKELJ, B. & RITONJA, A. 2000. Clitocypin, a new type of cysteine proteinase inhibitor from fruit bodies of mushroom *Clitocybe nebularis*. *Journal of Biological Chemistry* 275: 20104–20109.
- CARHART-HARRIS, R.L., ROSEMAN, L., BOLSTRIDGE, M., DEMETRIU, L., PANNEKOEK, J.N., WALL, M.B., TANNER, M., KAELEN, M., MCGONIGLE, J., MURPHY, K., LEECH, R., CURRAN, H.V. & NUTT, D.J. 2017. Psilocybin for treatment-resistant depression: fMRI-measured brain mechanisms. *Scientific Reports* 7.
- CARVAJAL, A.E.S.S., KOEHNLEIN, E.A., SOARES, A.A., ELER, G.J., NAKASHIMA, A.T.A., BRACHT, A. & PERALTA, R.M. 2012. Bioactives of fruiting bodies and submerged culture mycelia of *Agaricus brasiliensis* (A. blazei) and their antioxidant properties. *LWT - Food Science and Technology* 46: 493–499.
- CHAMBERLAIN, J., BUSH, R. & HAMMETT, A. 1998. Non-timber forest products: the other forest products. *Forest Products Journal* 48: 10–19.
- CHAN, H. 1981. Consumption of edible mushroom in Hong Kong. *Mushroom Newsletter for the Tropics* 1: 18–22.
- CHANG, S. & MILES, P. 1982. Introduction to mushroom science. In *Tropical Mushrooms—Biological Nature and Cultivation Methods*. Ed. Chang, S.T. & Quimio, T.H. Hong Kong, Chinese University Press, pp 437–441.
- CHANG, S.-T. 1999. Global impact of edible and medicinal mushrooms on human welfare in the 21st century: Nongreen revolution. *International Journal of Medicinal Mushrooms*. 1: 1–7.
- CHANG, S.-T. 2006. The world mushroom industry: Trends and technological development. *International Journal of Medicinal Mushrooms* 8: 297–314.
- CHANG, S.-T. & MILES, P. 2004. *Mushrooms*. 2nd ed., Boca Raton, CRC Press.
- CHATTERJEE, S., BISWAS, G. & BASU, S.K. 2011. Antineoplastic effect of mushrooms: a review. *Australian Journal of Crop Science* 5: 904–911.
- CHEN, C.-C., SHIAO, Y.-J., LIN, R.-D., SHAO, Y.-Y., LAI, M.-N., LIN, C.-C., NG, L.-T. & KUO, Y.-H. 2006. Neuroprotective diterpenes from the fruiting body of *Antrodia camphorata*. *Journal of Natural Products* 69: 689–691.
- CHEN, R.Y. & YU, D.Q. 1993. Studies on the triterpenoid constituents of the spores from *Ganoderma lucidum*. *Karst. Journal of Chinese Pharmaceutical Sciences* 2: 91–96.
- CHEN, S.-Y., HO, K.-J., HSIEH, Y.-J., WANG, L.-T. & MAU, J.-L. 2012. Contents of lovastatin, γ -aminobutyric acid and ergothioneine in mushroom fruiting bodies and mycelia. *Lebensmittel-Wissenschaft und Technologie* 47: 274–278.
- CHEUNG, L.M. & CHEUNG, P.C.K. 2005. Mushroom extracts with antioxidant activity against lipid peroxidation. *Food Chemistry* 89: 403–409.
- CHEUNG, P.C.K. 2013. Mini review on edible mushrooms as source of dietary fiber: Preparation and health benefits. *Food Science and Human Wellness* 2: 162–166.
- CHIBATA, I., OKUMURA, K., TAKEYAMA, S. & KOTERA, K. 1969. Lentinacin: a new hypocholesterolemic substance in *Lentinus edodes*. *Experientia* 25: 1237–1238.
- CHIHARA, G., MAEDA, Y., HAMURO, J., SASAKI, T. & FUKUOKA, F. 1969. Inhibition of mouse sarcoma 180 by polysaccharides from *Lentinus edodes* (Berk.) Sing. *Nature* 222: 687–688.

- CHOWDHURY, M., KUBRA, K. & AHMED, S. 2015. Screening of antimicrobial, antioxidant properties and bioactive compounds of some edible mushrooms cultivated in Bangladesh. *Annals of Clinical Microbiology and Antimicrobials* 14: 8.
- CHU, K.T., XIA, L. & NG, T.B. 2005. Pleurostrin, an antifungal peptide from the oyster mushroom. *Peptides* 26: 2098–2103.
- COHEN, L., PERSKY, Y. & HADAR, R. 2002. Biotechnological applications and potential of wood-degrading mushrooms of the genus *Pleurotus*. *Applied Microbiology and Biotechnology* 58: 582–594.
- CÔTÉ, J., CAILLET, S., DOYON, G., SYLVAIN, J.-F. & LACROIX, M. 2010. Bioactive compounds in cranberries and their biological properties. *Critical Reviews in Food Science and Nutrition* 50: 666–679.
- ČTRNÁCTÁ, V., FRITZLER, J.M., ŠURINOVÁ, M., HRDÝ, I., ZHU, G. & STEJSKAL, F. 2010. Efficacy of S-adenosylhomocysteine hydrolase inhibitors, D-eritadenine and (S)-DHPA, against the growth of *Cryptosporidium parvum* *in vitro*. *Experimental Parasitology* 126: 113–116.
- DAI, Y.-C., ZHOU, L.-W., CUI, B.-K., CHEN, Y.-Q. & DECOCK, C. 2010. Current advances in *Phellinus* sensu lato: medicinal species, functions, metabolites and mechanisms. *Applied Microbiology and Biotechnology* 87: 1587–1593.
- DHAKAL, R., BAJPAL, V.K. & BAEK, K.-H. 2012. Production of gaba (γ -aminobutyric acid) by microorganisms: a review. *Brazilian Journal of Microbiology* 43: 1230–1241.
- DUBOST, N.J., OU, B. & BEELMAN, R.B. 2007. Quantification of polypeptides and ergothioneine in cultivated mushrooms and correlation to total antioxidant capacity. *Food Chemistry* 105 (727e): 735.
- DWYER, S. 2010. Mushrooms: The Spawning of an Industry. Co-operator.
- EL-MEKKAWY, S., MESELYH, M.R., NAKAMURA, N., TEZUKA, Y., HATTORI, M., KAKIUCHI, N., SHIMOTOHNO, K., KAWAHATA, T. & OTAKE, T. 1998. Anti-HIV-1 and anti-HIV-1-protease substances from *Ganoderma Lucidum*. *Phytochemistry* 49: 1651–1657.
- ELSAYED, E.A., EL ENSHASY, H., WADAAN, M.A.M. & AZIZ, R. 2014. Mushrooms: A potential natural source of anti-inflammatory compounds for medical applications. *Mediators of Inflammation* 2014: 1–15.
- ENMAN, J., HODGE, D., BERGLUND, K.A. & ROVA, U. 2008. Production of the bioactive compound eritadenine by submerged cultivation of Shiitake (*Lentinus edodes*) mycelia. *Journal of Agricultural and Food Chemistry* 56: 2609–2612.
- EO, S.-K., KIM, Y.-S., LEE, C.-K. & HAN, S.-S. 1999. Antiviral activities of various water and methanol soluble substances isolated from *Ganoderma lucidum*. *Journal of Ethnopharmacology* 68: 129–136.
- FEKADU, A. 2014. Cultivation of *Pleurotus ostreatus* on *Grevillea robusta* leaves at Dilla University, Ethiopia. *Journal of Yeast and Fungal Research* 5: 74–83.
- FENG, Z., FANG, T.J., QIAN, Y.X. & RONG, W.H. 2014. The clinical research for Ganoderan's effect on preventing and treating cerebral arteriosclerosis through inhibiting NADPH oxidizing enzyme expression. *Pakistan Journal of Pharmaceutical Sciences* 27: 1107–1111.
- FIRENZUOLI, F., GORI, L. & LOMBARDO, G. 2008. The medicinal mushroom *Agaricus blazei* Murrill: Review of literature and pharmacotoxicological problems. *Evidence-Based Complementary and Alternative Medicine* 5: 3–15.
- FLOREZAK, J., KARMSKA, A. & WEDZISZ, A. 2004. Comparison of the chemical contents of the selected wild growing mushrooms. *Bromatology and Chemical Toxicology* 37: 365–371.
- FOMBANG, E., LOBE, E. & MBOFUNG, C. 2016. *Pleurotus florida* aqueous extracts and powder influence lipid profile and suppress weight gain in rats fed high cholesterol diet. *Journal of Nutrition and Food Sciences* 6: 473 (1–7). doi:10.4172/2155-9600.1000473
- FRANK, J.L., COFFAN, R.A. & SOUTHWORTH, D. 2010. Aquatic gilled mushrooms: *Psathyrella* fruiting in the Rogue River in southern Oregon. *Mycologia* 102: 93–107.
- FRANZONI, F., COLOGNATO, R., GALETTA, F., LAURENZA, I., BARSOTTI, M., DI STEFANO, R., BOCCHETTI, R., REGOLI, F., CARPI, A., BALBARINI, A., MIGLIORE, L. & SANTORO, G. 2006. An *in vitro* study on the free radical scavenging capacity of ergothioneine: comparison with reduced glutathione, uric acid and trolox. *Biomedicine and Pharmacotherapy* 60: 453–457.
- GAMBATO, G., TODESCATO, K., PAVÃO, E.M., SCORTEGAGNA, A., FONTANA, R.C., SALVADOR, M. & CAMASSOLA, M. 2016. Evaluation of productivity and antioxidant profile of solid-state cultivated macrofungi *Pleurotus albidus* and *Pycnoporus sanguineus*. *Bioresource Technology* 207: 46–51.
- GANESAN, K. & XU, B. 2018. Anti-Obesity effects of medicinal and edible mushrooms. *Molecules* 23: 2880.
- GANESAN, N., BASKARAN, R., VELMURUGAN, B.K. & THANH, N.C. 2019. *Antrodia cinnamomea*- An updated minireview of its bioactive components and biological activity. *Journal of Food Biochemistry*, 43(8): e12936. doi: 10.1111/jfbc.12936
- GAO, Y., ZHOU, S., CHEN, G., DAI, X., YE, J. & GAO, H. 2002. A Phase I/II study of a *Ganoderma lucidum* (Curt.: Fr.) P. Karst. (Ling Zhi, Reishi mushroom) extract in patients with chronic hepatitis B. *International Journal of Medicinal Mushrooms* 4: 7.
- GUILLAMÓN, E., GARCÍA-LAFUENTE, A., LOZANO, M., D'ARRIGO, M., ROSTAGNO, M.A., VILLARES, A. & MARTÍNEZ, J.A. 2010. Edible mushrooms: Role in the prevention of cardiovascular diseases. *Fitoterapia* 81: 715–723.
- HAN, J., CHEN, Y., BAO, L., YANG, X., LIU, D., LI, S., ZHAO, F. & LIU, H. 2013. Anti-inflammatory and cytotoxic cyathane diterpenoids from the medicinal fungus *Cyathus africanus*. *Fitoterapia* 84: 22–31.
- HELENO, S.A., BARROS, L., SOUSA, M.J., MARTINS, A. & FERREIRA, I.C.F.R. 2010. Tocopherol's composition of Portuguese wild mushrooms with antioxidant capacity. *Food Chemistry* 119: 1443–1450.
- Hirose, K., HAKOZAKI, M., KAKUCHI, J., MATSUNAGA, K., YOSHIKUMI, C., TAKAHASHI, M., TOCHIKURA, T.S. & YAMAMOTO, N. 1987. A biological response modifier, PSK, inhibits reverse transcriptase *in vitro*. *Biochemical and Biophysical Research Communications* 149: 562–567.
- INA, K., KATAOKA, T. & ANDO, T. 2013. The use of lentinan for treating gastric cancer. *Anti-Cancer Agents in Medicinal Chemistry* 13: 681–688.
- Isaka, M., Palasarn, S., Sommai, S., Veeranondha, S., Srichomthong, K., Kongsaree, P. & Prabpai, S. 2017. Lanostane triterpenoids from the edible mushroom *Astraeus asiaticus*. *Tetrahedron* 73: 1561–1567.
- ISAKA, M., PALASARN, S., SRIKITIKULCHAI, P., VICHAI, V. & KOMWIJIT, S. 2016. ChemInform abstract: *Astraeus* A-L, lanostane triterpenoids from the edible mushroom *Astraeus odoratus*. *ChemInform* 47.
- JABLONSKA-RYŚ, E., SKRZYPCZAK, K., SŁAWIŃSKA, A., RADZKI, W. & GUSTAW, W. 2019. Lactic acid fermentation of edible mushrooms: Tradition, technology, current state of research: A review. *Comprehensive Reviews in Food Science and Food Safety* 18: 655–669.
- JAKOVLEV, J. 2011. Fungus gnats (Diptera: Sciarioidea) associated with dead wood and wood growing fungi: new rearing data from Finland and Russian Karelia and general analysis of known larval microhabitats in Europe. *Entomologica Fennica* 22(3): 157–189.
- JESENAK, M., URBANCEK, S., MAJTAN, J., BANOVČIN, P. & HERCOGOVA, J. 2015. β -Glucan-based cream (containing pleuran isolated from *Pleurotus ostreatus*) in supportive treatment of mild-to-moderate atopic dermatitis. *Journal of Dermatological Treatment* 27: 351–354.
- JIAN-WEN, T., ZE-JUN, D., ZHI-HUI, D. & JI-KAI, L. 2002. Lepidolide, a novel seco-ring-A cucurbitane triterpenoid from *Russula lepida* (Basidiomycetes). *Zeitschrift für Naturforschung C* 57: 963–965.
- KALAČ, P. 2001. A review of edible mushroom radioactivity. *Food Chemistry* 75: 29–35.
- KANEDA, T. & TOKUDA, S. 1966. Effect of various mushroom preparations on cholesterol levels in rats. *The Journal of Nutrition* 90: 371–376.
- KEONG, C.Y. 2015. Medicinal values of selected mushrooms with special reference to anti-hypercholesterolemia. *Hypercholesterolemia*.
- KHATUN, S., ISLAM, A., CAKILCIOGLU, U. & CHATTERJEE, N.C. 2012. Research on mushroom as a potential source of nutraceuticals: A review on

- Indian perspective. *American Journal of Experimental Agriculture* 2: 47–73.
- KIM, G.-Y., KIM, S.-H., HWANG, S.-Y., KIM, H.-Y., PARK, Y.-M., PARK, S.-K., LEE, M.-K., LEE, S.-H., LEE, T.-H. & LEE, J.-D. 2003. Oral administration of proteoglycan isolated from *Phellinus linteus* in the prevention and treatment of collagen-induced arthritis in mice. *Biological and Pharmaceutical Bulletin* 26: 823–831.
- KIM, M.-Y., SEGUIN, P., AHN, J.-K., KIM, J.-J., CHUN, S.-C., KIM, E.-H., SEO, S.-H., KANG, E.-Y., KIM, S.-L., PARK, Y.-J., RO, H.-M. & CHUNG, I.-M. 2008. Phenolic compound concentration and antioxidant activities of edible and medicinal mushrooms from Korea. *Journal of Agricultural and Food Chemistry* 56: 7265–7270.
- KO, D.T., HEBERT, P.R., COFFEY, C.S., CURTIS, J.P., FOODY, J.M., SEDRAKYAN, A. & KRUMHOLZ, H.M. 2004. Adverse effects of beta-blocker therapy for patients with heart failure: a quantitative overview of randomized trials. *Archives of Internal Medicine* 164: 1389–94.
- KODAMA, N., KOMUTA, K. & NANBA, H. 2003. Effect of Maitake (*Grifola frondosa*) D-fraction on the activation of NK cells in cancer patients. *Journal of Medicinal Food* 6: 371–377.
- KONNO, S., AYNEHCHI, S., DOLIN, D.J., SCHWARTZ, A.M., CHOUDHURY, M.S. & TAZAKI, H. 2002. Anticancer and hypoglycemic effects of polysaccharides in edible and medicinal Maitake mushroom. *International Journal of Medicinal Mushrooms* 4: 185–195.
- KOVACIC, P., SOMANATHAN, R. & ABADJIAN, M.-C. 2015. Natural monophenols as therapeutics, antioxidants and toxins; electron transfer, radicals and oxidative stress. *The Natural Products Journal* 5: 142–151.
- KOYAMA, Y., KATSUNO, Y., MIYOSHI, N., HAYAKAWA, S., MITA, T., MUTO, H., ISEMURA, S., AOYAGI, Y. & ISEMURA, M. 2002. Apoptosis induction by lectin isolated from the mushroom *Boletopsis leucomelasma* U937 Cells. *Bioscience, Biotechnology, and Biochemistry* 66: 784–789.
- KUMAR, K.J.S., VANI, M.G., CHUEH, P.-J., MAU, J.-L. & WANG, S.-Y. 2015. Antrodin C inhibits epithelial-to-mesenchymal transition and metastasis of breast cancer cells via suppression of Smad2/3 and β -Catenin signaling pathways. *PLOS ONE* 10: e0117111.
- LAVI, I., LEVINSON, D., PERI, I., TEKOA, Y., HADAR, Y. & SCHWARTZ, B. 2009. Chemical characterization, antiproliferative and antiadhesive properties of polysaccharides extracted from *Pleurotus pulmonarius* mycelium and fruiting bodies. *Applied Microbiology and Biotechnology* 85: 1977–1990.
- LAVI, I., NIMRI, L., LEVINSON, D., PERI, I., HADAR, Y. & SCHWARTZ, B. 2011. Glucans from the edible mushroom *Pleurotus pulmonarius* inhibit colitis-associated colon carcinogenesis in mice. *Journal of Gastroenterology* 47: 504–518.
- LEE, S.-S., LEE, P.-L., CHEN, C.-F., WANG, S.-Y. & CHEN, K.-Y. 2003. Antitumor Effects of Polysaccharides of *Ganoderma lucidum* (Curt.: Fr.) P. Karst. (Ling Zhi, Reishi Mushroom) (Aphyllphoromycetidae). *International Journal of Medicinal Mushrooms* 5: 16.
- LENZ, C., WICK, J. & HOFFMEISTER, D. 2017. Identification of ω -N-Methyl-4-hydroxytryptamine (Norpsilocin) as a psilocybe natural product. *Journal of Natural Products* 80: 2835–2838.
- LI, Y., ZHANG, G., NG, T.B. & WANG, H. 2010. A novel lectin with antiproliferative and HIV-1 reverse transcriptase inhibitory activities from dried fruiting bodies of the monkey head mushroom *Hericium erinaceum*. *Journal of Biomedicine and Biotechnology* 2010: 1–9.
- LIN, C.-H., SHEU, G.-T., LIN, Y.-W., YEH, C.-S., HUANG, Y.-H., LAI, Y.-C., CHANG, J.-G. & KO, J.-L. 2010. A new immunomodulatory protein from *Ganoderma microsporum* inhibits epidermal growth factor mediated migration and invasion in A549 lung cancer cells. *Process Biochemistry* 45: 1537–1542.
- LIU, Q., WANG, H. & NG, T.B. 2006. First report of a xylose-specific lectin with potent hemagglutinating, antiproliferative and anti-mitogenic activities from a wild ascomycete mushroom. *Biochimica et Biophysica Acta (BBA) - General Subjects* 1760: 1914–1919.
- LO, Y.-C., LIN, S.-Y., ULZIJARGAL, E., CHEN, S.-Y., CHIEN, R.-C., TZOU, Y.-J. & MAU, J.-L. 2012. Comparative study of contents of several bioactive components in fruiting bodies and mycelia of culinary-medicinal mushrooms. *International Journal of Medicinal Mushrooms* 14: 357–363.
- MANJUNATHAN, J. & KAVIYARASAN, V. 2010. Biotechnological applications of *Lentinus tuberregium* (Fr.): A South Indian edible mushroom. *European Journal of Biological Sciences* 4: 1.
- MARSHALL, E. & NAIR, N. 2009. Make money by growing mushrooms. *Mayell, M.* 2001. Maitake extracts and their therapeutic potential. *Alternative Medicine Review* 6: 48–60.
- MHD OMAR, N.A., ABDULLAH, S., ABDULLAH, N., KUPPUSAMY, U.R., AMEEN ABDULLA, M. & SABARATNAM, V. 2015. *Lentinus squarrosulus* (Mont.) mycelium enhanced antioxidant status in rat model. *Drug Design, Development and Therapy* 9: 5957.
- MIZUNO, M. & NISHITANI, Y. 2013. Immunomodulating compounds in Basidiomycetes. *Journal of Clinical Biochemistry and Nutrition* 52: 202–207.
- MIZUNO, T. 1999. The extraction and development of antitumor-active polysaccharides from medicinal mushrooms in Japan (Review). *International Journal of Medicinal Mushrooms* 1: 9–29.
- MOHER, D., LIBERATI, A., TETZLAFF, J. & ALTMAN, D.G. 2009. Preferred reporting items for systematic reviews and meta-analyses: The PRISMA Statement. *PLoS Medicine* 6: e1000097.
- MOTHANA, R.A.A., JANSEN, R., JÜLICH, W.-D. & LINDEQUIST, U. 2000. Ganomycins A and B, New antimicrobial farnesyl hydroquinones from the basidiomycete *Ganoderma pfeifferi*. *Journal of Natural Products* 63: 416–418.
- NANBA, H., HAMAGUCHI, A. & KURODA, H. 1987. The chemical structure of an antitumor polysaccharide in fruit bodies of *Grifola frondosa* (Maitake). *Chemical and Pharmaceutical Bulletin* 35: 1162–1168.
- NG, T.B. 1998. A review of research on the protein-bound polysaccharide (polysaccharopeptide, PSP) from the mushroom *Coriolus versicolor* (basidiomycetes: Polyporaceae). *General Pharmacology: The Vascular System* 30: 1–4.
- NGAI, P.H.K., ZHAO, Z. & NG, T.B. 2005. Agrocybin, an antifungal peptide from the edible mushroom *Agrocybe cylindracea*. *Peptides* 26: 191–196.
- NUKATA, M., HASHIMOTO, T., YAMAMOTO, I., IWASAKI, N., TANAKA, M. & ASAKAWA, Y. 2002. Neogrifolin derivatives possessing anti-oxidative activity from the mushroom *Albatrellus ovinus*. *Phytochemistry* 59: 731–737.
- OGAWA, K. 1993. Genetics and Breeding of Edible Mushrooms. Gordon and Breach Science Publishers. Philadelphia. 297–324.
- OLAWALE, F.O. & MUHAMMED, N.M. 2013. Fungi: A review on mushrooms. In book: Current trends in advancement of scientific research and opinion in applied microbiology and biotechnology. First Edition. Subha Ganguly. Science and Education Development Institute, Nigeria.
- OYETAYO, F.L., AKINDAHUNSI, A. & OYETAYO, V.O. 2007. Chemical profile and amino acids composition of edible mushrooms *Pleurotus sajorajju*. *Nutrition and Health* 18: 383–389.
- PALACIOS, I., LOZANO, M., MORO, C., D'ARRIGO, M., ROSTAGNO, M.A., MARTÍNEZ, J.A., GARCÍA-LAFUENTE, A., GUILLAMÓN, E. & VILLARES, A. 2011. Antioxidant properties of phenolic compounds occurring in edible mushrooms. *Food Chemistry* 128: 674–678.
- PATEL, S. & GOYAL, A. 2012. Recent developments in mushrooms as anti-cancer therapeutics: a review. *3 Biotech* 2: 1–15.
- PHILLIPS, R., REID, D., BRYAN, J. & AL, E. 2006. *Mushrooms*. London, Macmillan.
- PHOSRI, C., WATLING, R., SUWANNASAI, N., WILSON, A. & MARTÍN, M.P. 2014. A new representative of star-shaped fungi: *Astraeus sirindhorniae* sp. nov. from Thailand. *PLoS ONE* 9: e71160.
- RATHEE, S., DHARMENDER, R., DEEPTI, R., KUMAR, V. & RATHEE, P. 2012. Mushrooms as therapeutic agents. *Revista Brasileira de Farmacognosia* 22: 459–474.
- REN, L., PERERA, C. & HEMAR, Y. 2012. Antitumor activity of mushroom polysaccharides: a review. *Food and Function* 3: 1118.

- RESHETNIKOV, S.V. & TAN, K.-K. 2001. Higher basidiomycota as a source of antitumor and immunostimulating polysaccharides (Review). *International Journal of Medicinal Mushrooms* 3: 34.
- RUDAWSKA, M. & LESKI, T. 2005. Macro- and microelement contents in fruiting bodies of wild mushrooms from the Nostecka forest in west-central Poland. *Food Chemistry* 92: 499–506.
- SAGAR, A., GAUTAM, C. & SEHGAL, A.K. 2007. Studies on some medicinal mushrooms of Himachal Pradesh. *Indian Journal of Mushrooms* 25: 8–14.
- SANCHEZ, C. 2017. Reactive oxygen species and antioxidant properties from mushrooms. *Synthetic and Systems Biotechnology* 2: 13–22.
- SANDE, D., OLIVEIRA, G.P.D., MOURA, M.A.F.E., MARTINS, B.D.E.A., LIMA, M.T.N.S. & TAKAHASHI, J.A. 2019. Edible mushrooms as a ubiquitous source of essential fatty acids. *Food Research International* 125: 108524.
- SANO, M., YOSHINO, K., MATSUZAWA, T. & IKEKAWA, T. 2002. Inhibitory Effects of Edible Higher Basidiomycetes Mushroom Extracts on Mouse Type IV Allergy. *International Journal of Medicinal Mushrooms* 4: 5.
- SENTIL, K.K., GOKILA, V.M. & WANG, S.Y. 2017. Activation of Nrf2-mediated antioxidant genes by antrocin C prevents hyperglycemia-induced senescence and apoptosis in human endothelial cells. *Oncotarget* 8: 96568–96587.
- SHASHIREKHA, M., RAJARATHNAM, S. & BANO, Z. 2005. Effects of supplementing rice straw growth substrate with cotton seeds on the analytical characteristics of the mushroom, (Block & Tsao). *Food Chemistry* 92: 255–259.
- SINANOGLOU, V.J., ZOUMPOULAKIS, P., HEROPOULOS, G., PROESTOS, C., ĆIRIĆ, A., PETROVIC, J., GLAMOČLIJA, J. & SOKOVIC, M. 2014. Lipid and fatty acid profile of the edible fungus *Laetiporus sulphureus*. Antifungal and antibacterial properties. *Journal of Food Science and Technology* 52: 3264–3272.
- SINGH, D.R. 2017. A Review on Different Benefits of Mushroom. *IOSR Journal of Pharmacy and Biological Sciences* 12: 107–111.
- SINGH, M.P. 2000. Biodegradation of lignocellulosic wastes through cultivation of *Pleurotus sajorajii*. In Van Griensven, J.L.J.D. (Ed.) *Science and Cultivation of Edible Fungi*. Rotterdam, Balkema. pp. 517–521.
- SINGH, M.P. & GAUTAM, N.C. 2004. An overview of lignocellulose biotechnology. In Gautam, N.C. & Singh, M.P. (Eds.) *Recent Advances in Biotechnology*. New Delhi, Shree Publishers and Distributors. pp. 3–20.
- SINGH, M.P., RASTOGI, P.C., SRIVASTAVA, A.K. & VISHWAKARMA, N.K. 2008. Decolorization of azo dyes by white rot fungi *Pleurotus* species. *Poll. Res* 27: 365–369.
- SINGH, R.S., BHARI, R. & KAUR, H.P. 2010. Mushroom lectins: Current status and future perspectives. *Critical Reviews in Biotechnology* 30: 99–126.
- SINGH, S., WANG, H., CHAN, Y., PAN, W., DAN, X., YIN, C., AKKOUH, O. & NG, T. 2014. Lectins from Edible Mushrooms. *Molecules* 20: 446–469.
- SMITH, J.E., ROWAN, N.J. & TAN, K.-K. 2000. Functional Food Science and the Medicinal Mushrooms. *International Journal of Medicinal Mushrooms* 2: 9.
- SRISURICHAN, S., PIAPUKIEW, J., PUTHONG, S. & PORNPAAKAKUL, S. 2017. Lanostane triterpenoids, spiro-astraodoric acid, and astraodoric acids E and F, from the edible mushroom *Astraeus odoratus*. *Phytochemistry Letters* 21: 78–83.
- STAMETS, P. 2000. *Growing Gourmet and Medicinal Mushrooms*, 3rd ed. Berkeley, CA, Ten Speed Press.
- STAPLETON, P.A., GOODWILL, A.G., JAMES, M.E., BROCK, R.W. & FRISBEE, J.C. 2010. Hypercholesterolemia and microvascular dysfunction: interventional strategies. *Journal of Inflammation* 7: 54.
- SUZUKI, T., AMANO, Y., FUJITA, M., KOBAYASHI, Y., DOHRA, H., HIRAI, H., MURATA, T., USUI, T., MORITA, T. & KAWAGISHI, H. 2009. Purification, Characterization, and cDNA Cloning of a Lectin from the Mushroom *Pleurocybella porrigens*. *Bioscience, Biotechnology, and Biochemistry* 73: 702–709.
- TAOFIQ, O., FERNANDES, Â., BARROS, L., BARREIRO, M.F. & FERREIRA, I.C.F.R. 2017. UV-irradiated mushrooms as a source of vitamin D 2: A review. *Trends in Food Science & Technology* 70: 82–94.
- TSENG, Y.-H., YANG, J.-H. & MAU, J.-L. 2008. Antioxidant properties of polysaccharides from *Ganoderma tsugae*. *Food Chemistry* 107: 732–738.
- TSUKAGOSHI, S. 1984. Krestin (PSK). *Cancer Treatment Reviews* 11: 131–155.
- UKWURU, M.U., MURITALA, A. & EZE, L.U. 2018. Edible and Non-Edible Wild Mushrooms: Nutrition, Toxicity and Strategies for Recognition. *Journal of Clinical Nutrition Metabolism* 2: 1–9.
- URBAIN, P., VALVERDE, J. & JAKOBSEN, J. 2016. Impact on Vitamin D2, Vitamin D4 and Agaritine in *Agaricus bisporus* Mushrooms after Artificial and Natural Solar UV Light Exposure. *Plant Foods for Human Nutrition* 71: 314–321.
- VAMANU, E. 2013. In Vitro Antioxidant and Antimicrobial Activities of Two Edible Mushroom Mycelia Obtained in the Presence of Different Nitrogen Sources. *Journal of Medicinal Food* 16: 155–166.
- VAZ, J.A., HELENO, S.A., MARTINS, A., ALMEIDA, G.M., VASCONCELOS, M.H. & FERREIRA, I.C.F.R. 2010. Wild mushrooms *Clitocybe alexandri* and *Lepista inversa*: In vitro antioxidant activity and growth inhibition of human tumour cell lines. *Food and Chemical Toxicology* 48: 2881–2884.
- VINCETI, B., TERMOTE, C., ICKOWITZ, A., POWELL, B., KEHLENBECK, K. & HUNTER, D. 2013. The Contribution of Forests and Trees to Sustainable Diets. *Sustainability* 5: 4797–4824.
- WANG, H., YANG, G.H., WU, S.H., WANG, S.F., LI, G.Y., XU, W.K., MENG, L.S. & LI, Z.Y. 1994. Chemical studies of *Russula rosacea*. *Acta Pharmaceutica Sinica* 29: 39–43.
- WANG, H.X. & NG, T.B. 2005. Purification of a laccase from fruiting bodies of the mushroom *Pleurotus eryngii*. *Applied Microbiology and Biotechnology* 69: 521–525.
- WANG, J., WANG, H.X. & NG, T.B. 2007. A peptide with HIV-1 reverse transcriptase inhibitory activity from the medicinal mushroom *Russula paludosa*. *Peptides* 28: 560–565.
- WANI, B.A., BODHA, R.H. & WANI, A.H. 2010. Nutritional and medicinal importance of mushrooms. *Journal of Medicinal Plants Research* 4: 2598–2604.
- WANNET, W.J.B., HERMANS, J.H.M., VAN DER DRIFT, C. & OP DEN CAMP, H.J.M. 2000. HPLC detection of soluble carbohydrates involved in mannitol and trehalose metabolism in the edible mushroom *Agaricus bisporus*. *Journal of Agricultural and Food Chemistry* 48: 287–91.
- WITKOWSKA, A.M., ZUJKO, M.E. & MIRONCZUK-CHODAKOWSKA, I. 2011. Comparative study of wild edible mushrooms as sources of antioxidants. *International Journal of Medicinal Mushrooms* 13: 335–341.
- WONG, J.H., WANG, H.X. & NG, T.B. 2008. Marmorin, a new ribosome inactivating protein with antiproliferative and HIV-1 reverse transcriptase inhibitory activities from the mushroom *Hypsizygus marmoratus*. *Applied Microbiology and Biotechnology* 81: 669–674.
- WU, G.-S., GUO, J.-J., BAO, J.-L., LI, X.-W., CHEN, X.-P., LU, J.-J. & WANG, Y.-T. 2013. Anti-cancer properties of triterpenoids isolated from *Ganoderma lucidum* – a review. *Expert Opinion on Investigational Drugs* 22: 981–992.
- WU, S.-J., LEU, Y.-L., CHEN, C.-H., CHAO, C.-H., SHEN, D.-Y., CHAN, H.-H., LEE, E.-J., WU, T.-S., WANG, Y.-H., SHEN, Y.-C., QIAN, K., BASTOW, K.F. & LEE, K.-H. 2010. Camphorins A–J, potent cytotoxic and anti-inflammatory triterpenoids from the fruiting body of *Taiwanofungus camphoratus*. *Journal of Natural Products* 73: 1756–1762.
- XU, T. & BEELMAN, R.B. 2015. The bioactive compounds in medicinal mushrooms have potential protective effects against neurodegenerative diseases. *Advances in Food Technology and Nutritional Sciences - Open Journal* 1: 62–65.
- YADAV, M.C. 2004. *Molecular Markers in Genetics and Breeding of Mushroom*. New Delhi, Shree Publishers and Distributors.
- YANG, J.-H., LIN, H.-C. & MAU, J.-L. 2002. Antioxidant properties of several commercial mushrooms. *Food Chemistry* 77: 229–235.

- YE, M., LIU, J., LU, Z., ZHAO, Y., LIU, S., LI, L., TAN, M., WENG, X., LI, W. & CAO, Y. 2005. Grifolin, a potential antitumor natural product from the mushroom *Albatrellus confluens*, inhibits tumor cell growth by inducing apoptosis *in vitro*. *FEBS Letters* 579: 3437–3443.
- YEN, I.-C., SHI, L.-S., CHUNG, M.-C., AHMETAJ-SHALA, B., CHANG, T.-C. & LEE, S.-Y. 2018. Antrolone, a novel benzoid derived from *Antrodia cin-namomea*, inhibits the LPS-induced inflammatory response in RAW264.7 macrophage cells by balancing the NF- κ B and Nrf2 pathways. *The American Journal of Chinese Medicine* 46: 1297–1313.
- YILMAZ, N., SOLMAZ, M., TÜRKÜKUL, İ & ELMAS, M. 2006. Fatty acid composition in some wild edible mushrooms growing in the middle Black Sea region of Turkey. *Food Chemistry* 99: 168–174.
- YOO, Y.B. & CHA, D.Y. 1993. Gene transfer in edible fungi using proto-plasts. In Chang, S.T. & Buswell, J.A. (Eds.) *Genetics and Breeding of Edible Mushrooms*. Gordon and Breach Science Publishers. Philadelphia. 297–324.
- ZAMBONELLI, A. 2012. *Edible Ectomycorrhizal Mushrooms: Current Knowledge and Future Prospects*. Berlin, Springer.
- ZHANG, G.Q., SUN, J., WANG, H.X. & NG, T.B. 2009. A novel lectin with antiproliferative activity from the medicinal mushroom *Pholiota adiposa*. *Acta Biochimica Polonica* 56: 415–421.
- ZHANG, Q., HU, M., XU, L., YANG, X., CHANG, Y. & ZHU, Y. 2017. Effect of edible fungal polysaccharides on improving influenza vaccine protection in mice. *Food and Agricultural Immunology* 28: 981–992.
- ZHANG, Y., MILLS, G.L. & NAIR, M.G. 2002. Cyclooxygenase inhibitory and antioxidant compounds from the mycelia of the edible mushroom *Grifola frondosa*. *Journal of Agricultural and Food Chemistry* 50: 7581–7585.
- ZHANG, Y., MILLS, G.L. & NAIR, M.G. 2003. Cyclooxygenase inhibitory and antioxidant compounds from the fruiting body of an edible mushroom, *Agrocybe aegerita*. *Phytomedicine* 10: 386–390.