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Edible Mushroom: Nutritional Properties, Potential Nutraceutical Values, and Its Utilisation in Food Product Development

Lee-Hoon Ho, Noroul Asyikeen Zulkifli and Thuan-Chew Tan

Abstract

Edible mushrooms are an excellent source of proteins, minerals, polysaccharides, unsaturated fatty acids, and secondary metabolites. Numerous studies have provided evidence for the protective effects of edible mushrooms against various chronic diseases. In this review, details on the compositions and nutritional values of edible mushrooms were discussed. Furthermore, bioactive compounds such as polyphenolic compounds and antioxidant capacity of edible mushrooms, as well as the application of these edible mushrooms as potential therapeutic agents, were covered. This chapter also endeavoured to review the recent progress on the potential utilisation of edible mushrooms in the development of functional food products and its effects on the nutritional, physical, and organoleptic properties of the developed food products. Based on the recent socioeconomic trends, the substitution of edible mushroom as an essential source of functional ingredients in food products could become a natural adjuvant for the prevention and alleviation of several lifestyle-related diseases. This information could be beneficial for the development of food products with health functionalities, which are of great interest to the medical nutrition industry, which is an industry that emerged from the convergence between the food and pharma industries.

Keywords: edible mushroom, nutritional compositions, functional properties, nutraceutical properties, therapeutic values, food product quality

1. Introduction

Mycophagy describes the practice of eating mushrooms. This practice can be dated back to ancient times, whereby wild edible mushrooms were collected and consumed. Mushrooms are an excellent source of vitamins, e.g. B vitamins and vitamin D [1], and minerals, e.g. phosphorus, magnesium, selenium, copper, and potassium [2], and are also rich in dietary fibre, chitin and β -glucans [3]. Humans have, for centuries, consumed mushrooms not only for nutrition [4, 5] and taste [6] but also for their healing properties [7]. Numerous studies have shown that mushrooms are a rich source of bioactive compounds, e.g. phenolic and flavonoid compounds, that exert antioxidant properties, and these could be beneficial to

human health [8–12]. Mushrooms could help in reducing the risk of diseases, such as Parkinson’s, Alzheimer’s, hypertension, stroke, and cancer, as well as act as an antibacterial, immune system enhancer, and cholesterol-lowering agents [13].

Due to the numerous reports and findings on the health benefits of mushrooms to humans, studies on the use of mushrooms as a bioactive ingredient in functional food products have gained attention from the scientific community. Mushrooms are converted into powder before incorporated into food products, such as bread, muffins, pasta, patties, and snacks, to increase the nutritional quality of these products [14–18]. With the introduction of processed food products incorporated with mushrooms, this further expands the popularity of mushrooms among consumers. On average, consumers consumed about 5 kg of mushrooms per person per year, and this number is expected to continue to increase as consumers become more aware of the healthful benefits of incorporating mushrooms in their diet [19].

For the last 10 years, from 2008 to 2017, the global production of mushrooms and truffles grew from 6.90 to 10.24 million metric tons [20] (**Figure 1**). Based on the latest statistic report from the Food and Agriculture Organization of the United Nations, in 2017, China (7.87 million metric tons, contributed almost 77% of world production), the United States (0.42 million metric tons), the Netherlands (0.30 million metric tons), Poland (0.30 million metric tons), and Spain (0.16 million metric tons) were reported as the top 5 mushroom and truffle producers in the world. As the demand for edible mushrooms increases and the amount of wild edible mushrooms shrinks, edible mushroom cultivation is becoming an important agriculture sector.

The most cultivated edible mushroom worldwide is *Agaricus bisporus* (common mushroom) followed by *Lentinus edodes* (shiitake mushroom), *Pleurotus* spp. (in particular oyster mushroom), and *Flammulina velutipes* (enoki mushroom) [3, 13, 21]. Moisture content varies around 90% for raw mushrooms. Typically, mushrooms are low in fat and contain useful minerals and B vitamins. Though mushrooms are not energy-providing foods, mushrooms are a substantially better source of nutrition than is often assumed [22].

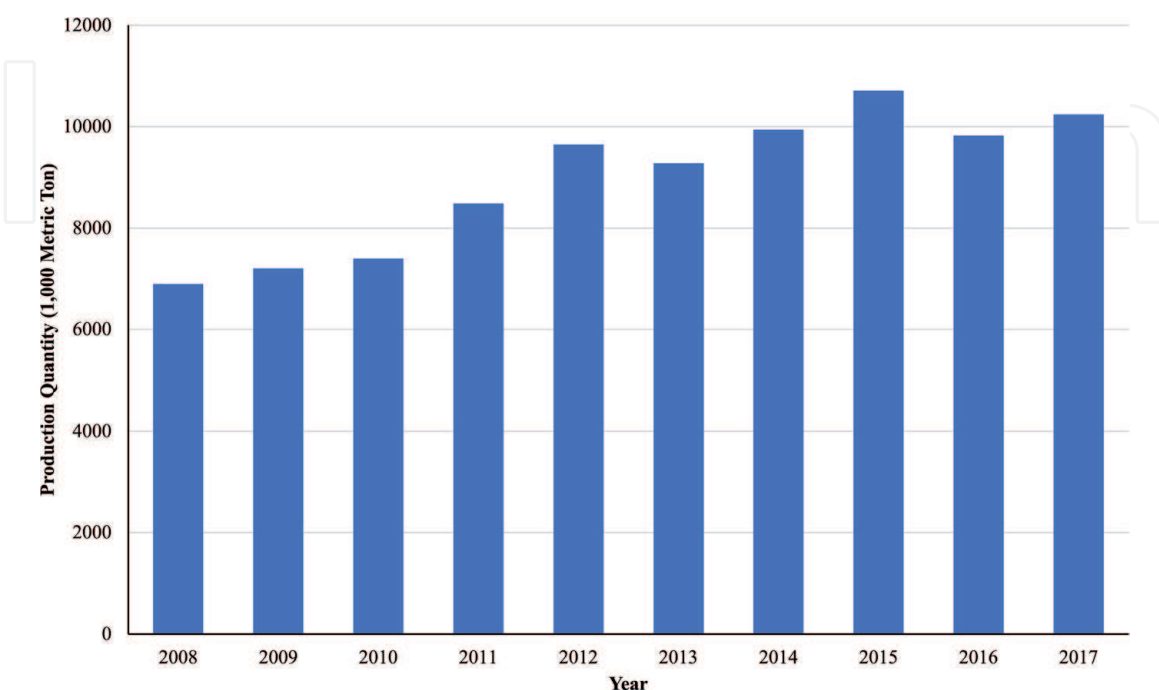


Figure 1. Growth in world mushrooms and truffles production, 2008–2017. Source: [20].

2. Nutritional compositions

Edible mushrooms possess high nutritional value, especially protein and carbohydrates. Besides, edible mushrooms have also been described as a rich source of minerals and vitamins [23, 24]. The mean nutrient values for these raw mushrooms [25] are presented in **Table 1**. Han et al. [24] studied the quality properties of powder processed from oyster mushroom, a variety of *Pleurotus sajor-caju* (PSC). Their results showed PSC powder had a high content of carbohydrate (60.47 g/100 g), resulting in 451.60 cal/g calorie. According to Samsudin and Abdullah [21], mushrooms provide both digestible carbohydrates (i.e. trehalose, mannitol, glycogen, and glucose) and non-digestible carbohydrate (i.e. mannans, chitin, and β -glucan). Later, both these carbohydrates form the larger portion of the total carbohydrates. Aremu et al. [26] reported that the calculated metabolisable energy values in *Ganoderma* spp. (1476.7 kJ/100 g) and in *Hebeloma mesophaeum* (1513.5 kJ/100 g) indicate that both varieties of mushrooms are concentrated sources of energy and compared favourably to cereals in terms of their energy values.

Nutrient	Common mushroom	Shiitake mushroom	Oyster mushroom	Enoki mushroom
Moisture (g/100 g)	92.45	89.74	89.18	88.34
Energy (kcal/100 g)	22	34	33	37
Protein (g/100 g)	3.09	2.24	3.31	2.66
Fat (g/100 g)	0.34	0.49	0.41	0.29
Ash (g/100 g)	0.85	0.73	1.01	0.91
Carbohydrate (g/100 g)	3.26	6.79	6.09	7.81
Dietary fibre (g/100 g)	1.0	2.5	2.3	2.7
Ergosterol (mg/100 g)	56	85	64	36
Calcium (mg/100 g)	3	2	3	0
Copper (mg/100 g)	0.32	0.14	0.24	0.11
Iron (mg/100 g)	0.5	0.41	1.33	1.15
Magnesium (mg/100 g)	9	20	18	16
Manganese (mg/100 g)	0.05	0.23	0.11	0.08
Phosphorus (mg/100 g)	86	112	120	105
Potassium (mg/100 g)	318	304	420	359
Selenium (μ g/100 g)	9.3	5.7	2.6	2.2
Sodium (mg/100 g)	5	9	18	3
Zinc (mg/100 g)	0.52	1.03	0.77	0.65
Thiamin (mg/100 g)	0.081	0.015	0.125	0.225
Riboflavin (mg/100 g)	0.40	0.22	0.35	0.20
Niacin (mg/100 g)	3.61	3.88	4.96	7.03
Pantothenic acid (mg/100 g)	1.50	1.50	1.29	1.35
Pyridoxine (mg/100 g)	0.10	0.29	0.11	0.10

Source: USDA [25].

Table 1.
 Mean nutrient content of raw mushrooms per 100 g edible portion.

On the other hand, Han et al. [24] reported that PSC contained 22.4 g/100 g protein, 56.99 g/100 g dietary fibre (i.e. 56.99 g/100 g total dietary fibre, 48.79 g/100 g insoluble dietary fibre, and 8.20 g/100 g soluble dietary fibre), 7.79 g/100 g ash, and 3.32 g/100 g β -glucan but has low amount of sucrose (0.19 g/100 g) and crude fat (2.30 g/100 g). According to Elleuch et al. [27], polysaccharides especially dietary fibres are the most important active compounds among others. Hence, several medicinal and pharmacological properties of PSC are believed to be associated with dietary fibre which can provide functional properties.

It is interesting to note that different parts of mushroom, the cap, stalk, or cap with a stalk of oyster mushroom (*Pleurotus ostreatus*), an edible mushroom, presented different proximate compositions [28]. The results showed that the stalk of mushrooms had the highest moisture content (6.33 g/100 g) than the other parts of mushrooms, whereas the cap showed the least moisture content (3.48 g/100 g). In addition, there was a noticeable difference in their protein content, 34.19 g/100 g of the cap, 20.96 g/100 g of a stalk, and 30.48 g/100 g of the cap with a stalk. Cruz-Solorio et al. [29] reported that the fruit body of *Pleurotus ostreatus* has significant nutritional values and highly valuable protein concentrates. Protein fractionation revealed that globulin had the highest proportion with 47.31% present in the cap, 23.31% in stalk, and 44.65% present in cap with a stalk, while albumin varied between 3.29 and 4.18% in cap, stalk, and cap with a stalk [28]. Moreover, the cap, stalk, and stalk with a cap were reported to have 3.14 g/100 g, 7.53 g/100 g, and 8.12 g/100 g, respectively, of crude fibre. The ash content was between 5.30 and 8.24 g/100 g for all parts of the mushroom; the fat content was 1.48 g/100 g, 1.55 g/100 g, and 1.5 g/100 g for the stalk, cap, and stalk with the cap, respectively. Carbohydrate content ranges between 51.94 and 61.77 g/100 g [28].

In another study by Kayode et al. [23], they found that the proximate compositions of exotic oyster mushroom grown on *Gmelina* wood waste and indigenous wild species of oyster mushroom (i.e. PSC) have 7.00 g/100 g and 7.15 g/100 g moisture, 19.30 g/100 g and 25.24 g/100 g protein, 7.24 g/100 g and 6.65 g/100 g crude fat, 7.47 g/100 g and 7.05 g/100 g crude fibre, 7.13 g/100 g and 8.25 g/100 g ash, and 51.86 g/100 g and 45.66 g/100 g total carbohydrate, respectively. This study concluded that oyster mushroom grown on *Gmelina* wood waste is favourably compared with the wild counterpart and has potential for use as acceptable human food [23].

According to Aremu et al. [26], *Ganoderma* sp., *Omphalotus olearius*, and *Hebeloma mesophaeum* are species reported to be among the most edible mushrooms commonly found in Nigeria. They evaluated the proximate composition of these three edible mushrooms. The evaluated samples contained moisture, crude protein, ash, crude fat, and total carbohydrate in the range of 10.0–11.1 g/100 g, 18.5–21.5 g/100 g, 7.3–8.3 g/100 g, 6.9–8.7 g/100 g, and 50.3–50.9 g/100 g, respectively. Moreover, Valverde et al. [13] reported that the major fatty acids found in mushrooms are linoleic (C18:2), oleic (C18:1), and palmitic (C16:0). Besides, there was also a mild amount of crude fibre (2.8–3.5 g/100 g) present in the evaluated mushroom [26]. This can be concluded that the nutritional content of mushrooms does not only depend on environmental factors but also on species.

Ishara et al. [30] fortified the maize flour with mushroom flour from *Agaricus bisporus* and *Pleurotus ostreatus*, aimed to improve the nutritional values of the flour. To this, the compositional characteristics and their interactions were investigated. Overall, the protein content of maize flour increased with increased mushroom flour content from 6.9 g/100 g to 15.87 g/100 g (*Agaricus bisporus*) up to 19.32 g/100 g (*Pleurotus ostreatus*), and a significant increase in fibre (0.53–5.89 g/100 g) was observed [30]. Overall, edible mushrooms contain a high amount and good quality protein content for approximately 20–40 g/100 g of dry weight basis [31]. They are

ranked to be richer than most food sources except meat in terms of protein content [32]. Besides, the mushroom also contains several amino acids that cannot be derived by a human: phenylalanine, lysine, isoleucine, leucine, valine, histidine, threonine, methionine, glutamic acids, and aspartic [5, 33]. To this, glutamic acids and aspartic are the two essential amino acids that give the property umami taste of mushrooms [34]. Therefore, mushroom provides balancing diet compounds in sufficient amounts for human health.

Further, Alexopolous et al. [35] reported that the fairy ring mushroom (*Marasmius oreades*) is a good edible species containing copper, iron, zinc, folic acid, and all the essential amino acids required by a human. In addition, *Lentinula edodes* is reported to have low sodium and glucose, which are ideal for diabetics [35]. In another report, several predominant minerals such as potassium, magnesium, calcium, and iron are found in both exotic cultivated oyster mushrooms and indigenous wild oyster mushrooms. However, most of the mineral values are lower in exotic cultivated mushrooms as compared with that wild oyster mushroom. Oluwafemi et al. [28] reported that phosphorus, magnesium, and potassium were the major abundant minerals in mushroom with 497.35 mg/100 g in the cap, 340.59 mg/100 g stalk, and 466.24 mg/100 g caps with a stalk. Also, according to Kalač [36], potassium is the major element in edible mushrooms. It was reported that potassium is unevenly distributed within the different parts of mushroom fruit bodies; potassium is found to accumulate most concentration in a cap, followed by stipe, spore-forming part, and the least in spores. Magnesium is the second major mineral after potassium found in wild edible mushrooms [36]. Interestingly, sodium is found to present the lowest concentration among all evaluated minerals in the mushrooms [36, 37]. On the other hand, the fortification of maize flour with mushroom powder resulting in the mineral content increased from 2.84 to 8.74 mg/100 g for iron and 3.13 to 5.41 mg/100 g for zinc in the composite flours [30].

Another study was performed on the determination of β -carotene (vitamins A); α -tocopherol and γ -tocopherol for vitamin E, ascorbic acid (vitamin C), thiamine (vitamin B1), and riboflavin (vitamin B2); and several dominant and trace minerals on selected wild edible mushrooms, namely, *Pleurotus* sp., *Hygrocybe* sp., *Hygrophorus* sp., *Schizophyllum commune*, and *Polyporus tenuiculus*. The results revealed that *Schizophyllum commune* had the highest vitamins A and E for approximately 2711.30 mg/g fresh weight and 85.08 mg/g fresh weight, respectively. For other wild edible mushrooms tested, except *Pleurotus* sp., vitamins C, B1, and B2 were found mild [38]. According to Keegan et al. [39], mushrooms generally lacked in vitamin D₂. However, they can act as a biological precursor to vitamin D₂ due to the presence of ergosterol, a type of sterol predominantly found in mushrooms. Therefore, this feature indirectly makes mushrooms as an excellent source for vitamin D₂.

3. Functional properties

The functional properties of flours play an important role in determining the level of utilisation in ingredient formulation as well as in food product development. It is important to recognise the functional properties (i.e. water absorption capacity, oil absorption capacity, emulsifying, foaming, and gelification ability) of mushroom flours for their efficient use and acceptance by consumers [40]. The analysis of functional properties, water absorption capacity, oil absorption capacity, oil emulsion capacity, foaming stability, foaming capacity, least gelation concentration, and bulk density on flour prepared from *Ganoderma* spp., *Omphalotus olearius*, and *Hebeloma mesophaeum* provided interesting findings [26]. The functional properties' results of all the tested edible mushrooms demonstrated that they contained water absorption

capacity ranges from 260.0 to 390.0%, 450–480% of oil absorption capacity, 57.3–61.0 mL/g of oil emulsion capacity, foaming stability (51.0–54.0%), foaming capacity ranges from 101.8 to 131.5%, least gelation concentration 12.0–14.0%, and 230.0–410.0 g/mL of bulk density [26]. Moreover, Aremu et al. [26] concluded that the results of forming stability after 24 h for *Ganoderma* spp., *Omphalotus olearius*, and *Hebeloma mesophaeum* reflected that the studied mushroom samples might be attractive for incorporation into meat or bakery products like cakes or whipping topping where oil absorption and foaming are, respectively, important [26]. *Pleurotus sajor-caju* powder presented notable functional properties such as water holding capacity (13.46 g/g), oil holding capacity (8.52 mL/g), swelling capacity (19.49 mL/g), emulsifying activity (51.67%), and emulsifying stability (95.37%) [24].

Cruz-Solorio et al. [29] evaluated the functional properties of flours processed from fruit bodies of three *Pleurotus ostreatus* strains: a strain from commercial (POS), a culture collection strain (PCM) and a hybrid derived from POS and PCM (POS × PCM), and protein concentrates. The authors described pale yellow flours that were obtained from all three strains of edible mushrooms, while greyish brown was observed for protein concentrates. They recorded that the bulk density of the processed flour was to be ranged from 0.52 to 0.64 g/mL which showed higher than that of protein concentrates (0.30–0.35 g/mL). For water absorption capacities, 300–118.8% was obtained for flours, while protein concentrates demonstrated higher oil absorption capacity than the flours. Meanwhile, flours and protein concentrates showed a minimal gelation concentration (2%). For foam capacity formation, protein concentrates presented a higher value than that of flour at pH 8.0. However, for foam stability, both flours and protein concentrates showed high value at pH 8.0 and pH 10.0 (alkaline conditions). The flours presented have 3.96–26.68 m²/g of emulsion activity index, whereas protein concentrates range from 1.55 to 10.28 m²/g. The authors concluded that flours and protein concentrates produced from *Pleurotus ostreatus* presented remarkable functional properties and it has the potential to be used in the food industry where foaming and emulsifying properties are required [29].

In addition, another report by Oluwafemi et al. [28] on various parts of *Pleurotus ostreatus* showed that mushroom stalk (675%) had higher water absorption capacity than the cap (487%) and the mixture of stalk and cap (530%). The bulk density varied as 0.483 g/ml cap, 0.297 g/ml stalk, and 0.501 g/ml for a mixture of stalk and cap. Overall, the mushroom cap has the highest emulsion and foaming capacity of 17.33% and 30.67%, respectively. Ishara et al. [30] found that there was a positive significant linear effect in the substitution of mushroom flour (i.e. *Agaricus bisporus* and *Pleurotus ostreatus*) for maize flour on foam stability, foaming capacity, swelling capacity, solubility index, water retention capacity, water absorption capacity, and oil absorption capacity, but a negative linear effect was observed for the bulk density, compact density, and syneresis.

4. Nutraceutical properties

The importance of edible mushrooms as a nutraceutical source can be correlated to their composition and presence of phytochemicals. Reports have shown edible mushrooms to contain a wide array of bioactive compounds. These bioactive compounds present great potential to be applied as therapeutic agents. This is in agreement with the reports from Kozarski et al. [41], whereby the radical scavenging antioxidative activities of edible mushrooms come from an array of biomolecules from the carotenoid and polyphenol groups. Mushrooms are well-known to have rich various bioactive compounds that are widely used as raw material for the

development of functional foods. It could emerge as the nutraceutical food for the next generation [42]. According to Sánchez [43], phenolic compounds such as myricetin, quercetin, caffeic acid, catechin, and pyrogallol are present in all edible mushrooms. Besides, antioxidant components (i.e. phenolics, carotenoids, ascorbic acid, tocopherols, ergosterol, and polysaccharides) are mainly found constituted in both fruit bodies, mycelium, and culture of mushrooms [43].

Different edible mushroom cultivars and wild species are reported to possess varied concentrations of phytochemicals and antioxidant activities. Kayode et al. [23] reported that qualitative analysis of oyster mushroom grown on *Gmelina* wood waste and the indigenous wild species of oyster mushroom showed the presence of the five major phytochemicals: alkaloid, tannin, flavonoid, saponin, and cardiac glycosides. In addition, for the quantitative analysis, alkaloid presented as the most predominant phytochemical in both evaluated samples: 10.05% for oyster mushroom grown on *Gmelina* wood waste and 9.64% for indigenous wild species. The authors concluded that oyster mushroom grown on *Gmelina* wood waste could compare favourably with the indigenous wild species counterpart on the phytochemical compositions [23]. Total polyphenols are the dominant naturally occurring antioxidant components found in the wild edible mushrooms that show great scavenging ability due to their hydroxyl groups [44, 45].

Radzki et al. [46] studied the effect of hydrothermal treatment (i.e. citric acid solution blanching (5 min) and oiling in water (15 min)) on the antioxidant capacity (i.e. ferric-reducing antioxidant power assay (FRAP), and scavenging ability on 1,1-diphenyl-2-picrylhydrazyl (DPPH) assays) of three species of edible mushroom, namely, *Pleurotus ostreatus*, *Agaricus bisporus*, and *Lentinula edodes*. The results showed that water extracts for nontreatment mushrooms (control) contained noticeably more phenolic compounds. Both the water and ethanolic extracts for *Agaricus bisporus* possessed the highest content of total phenolic compounds and antioxidant capacity, but the lowest content was found in *Lentinula edodes*. Overall, the authors concluded that the blanching and oiling processes caused a decrease in the antioxidant activity. However, in terms of hydrothermal resistance, *Pleurotus ostreatus* was the most vulnerable [46]. Another report by Mau et al. [47] demonstrated that the methanolic extract of *Termitomyces albuminosus* mycelia has high antioxidant properties. On the other hand, an aqueous extract of *Agaricus blazei* was a potent free radical scavengers and is possible to be used as a pharmacological agent against oxidative stress [48]. Several factors may influence the antioxidant activity of mushroom including the development of fruiting bodies and culture conditions, processing conditions in industrial and domestic environments, and digestion and absorption in human intestinal [49].

Mujić et al. [44] evaluated the potential antioxidant activity content of antioxidant compounds, phenolics and flavonoids, and scavenging capacity on DPPH radicals of three edible mushroom species *Lentinula edodes*, *Herichium erinaceus*, and *Agrocybe aegerita*. *Agrocybe aegerita* showed to have the highest total phenolics (23.07 mg GAE/g) and total flavonoids (5.04 mg CE/g) content. Radical scavenging activity was found to exhibit IC₅₀ value for extract concentration of 0.198 mg/mL for *Herichium erinaceus*, 0.073 mg/mL for *Lentinula edodes*, and lower than 0.02 mg/mL for *Agrocybe aegerita*. The highest antioxidant activity of *Agrocybe aegerita* extract is in relation to its highest total phenols content. Therefore, *Agrocybe aegerita* could be considered as a raw material with high potential antioxidant activity [44].

Keleş et al. [45] evaluated total phenolic and antioxidant activity in the methanolic extracts of 24 types of dried wild edible mushrooms. The authors concluded that mushrooms contain 420–12775.56 mg/kg of phenolics and the FRAP and DPPH values range between 145.50–62771.43 µmol/g and 10.17–97.96% of dried matter, respectively; the total phenolics in methanolic extracts were the highest in *Boletus edulis*,

whereas the methanolic extracts from *Leccinum scabrum* showed most potent radical scavenging activity (97.96%). It was found that p-coumaric, p-hydroxybenzoic, protocatechuic, and cinnamic acids were contained in the phenolic fraction of five wild mushrooms from Portugal [50]. Thus, edible mushrooms may be applied as natural antioxidants in food products.

5. Therapeutic values

Apart from the nutritional values, edible mushrooms are also being used for a very long time to treat many types of diseases. Many of the common edible species have therapeutic properties and have been eaten for medical treatment purposes [51]. Many therapeutic values of mushrooms traditionally used in folklores of many parts of countries are being scientifically corroborated and have been found to stem from numerous biologically active and health-promoting metabolites that the mushrooms produce [21, 49]. Mushrooms have been reported as useful in preventing diseases such as hypertension, hypercholesterolemia, and cancer [44] due to the presence of high antioxidative compounds in mushrooms. The consumption of food containing antioxidant compounds like mushrooms will protect against the damage of cells from free radical, delays ageing, as well as prevent various diseases [43]. According to Zekovic et al. [52], mushrooms' β -glucans have been reported to exhibit different effects (i.e. antitumour, immune-booster) when compared with β -glucans from oats and barley (i.e. lowering cholesterol and blood sugar). Often, the β -glucans produced by specific mushroom species have specific names such as ganoderan (*Ganoderma lucidum*), grifolan (*Grifola fondosa*), lentinan (*Lentinus edodes*), pleuran (*Pleurotus ostreatus*), and schizophyllan (*Schizophyllum commune*) [53]. Apart from the immunomodulatory properties reported, mushrooms' β -glucans have also been documented to have antibacterial activity [54]. Many studies demonstrated that β -glucans, a water-soluble dietary of many edible mushrooms, are responsible for antioxidant, anticancer, anticholesterolaemic, immunomodulating, and neuroprotective activities. Furthermore, they are recognised as potent immunological stimulators in humans. Studies showed that β -glucans bind to a membrane receptor and induce these biological responses [55–57].

Valverde et al. [13] reported that several active compounds such as phenolics, ascorbic acid, carotenoids, and tocopherol isolated from the different species of mushrooms are responsible compounds to boost the immune system of the body and have anti-hypercholesterolaemic activity, antiviral activity, and anticancer, and ameliorate the toxic effect of chemo- and radiotherapy. The previous study conducted by Lau et al. [58] demonstrated that the protein extract from selected local edible mushrooms (i.e. *Pleurotus cystidiosus* and *Agaricus bisporus*) has high antihypertensive activities. Besides, Pleuran from *Pleurotus* spp. has shown marked immunity-stimulating effect and blood cholesterol-reducing effect, whereby proteoglycans possess immunomodulatory and antitumour activities [59]. A similar report was also presented by Li et al. [60]; a polysaccharide isolated from *Pholiota nameko* (PNPS-1) from the family of Strophariaceae leads to significant decreases in very low-density lipoprotein/low-density lipoprotein cholesterol and an increase in high-density lipoprotein cholesterol.

In Japan, lentinan, a complex carbohydrate, is isolated from a variety of mushrooms such as *Lentinula edodes* for the natural treatment of cancer. Lentinan is commonly used in clinic assays as an adjuvant in tumour therapy (i.e. chemotherapy and radiotherapy) [13]. *Lentinula edodes* is also a source of selenium, an antioxidant that is said to prevent cancer [35]. Bioactive proteins and peptides in mushrooms such as lectins, laccases, ribonucleases, antimicrobial proteins, fungal immunomodulatory proteins,

and ribosome-inactivating proteins have significant value for pharmaceutical use [61]. According to Zhang et al. [62], lectin isolated from *Pholiota adiposa* showed antiproliferative activity. Lectins are proteins or glycoproteins bound to the carbohydrate cell surface, specifically [63]. Other than that, *Flammulina velutipes* is rich in peroxidase, superoxide dismutase, and others and can prevent some severe diseases like cancer and coronary heart diseases [64]. A study by Qu et al. [65] showed that fatty acids that are extracted from *Hygrophorus eburneus* have antifungal and antibacterial activities. In addition, hygrophamides isolated from the fruiting bodies of *Hygrophorus eburneus* are important constituents of cell membranes that play important roles as antigens and their receptors. Aina et al. [66] recorded that the chanterelles, an edible mushroom species *Cantharellus cibarius*, have antimicrobial activities against yeast, filamentous fungi, Gram-negative and Gram-positive bacteria, as well as actinomycetes.

6. Functional foods from edible mushrooms

Mushrooms are generally traded in food industries in three categories, which are fresh, dried, or canned and processed as mushroom-based products [67]. Most of the fresh mushroom is used in soup, sauce, and as a filling in buns or pizzas. The fresh mushroom is usually sold in local markets due to its short shelf life. As reported by Akbarirad et al. [68], the shelf life of mushrooms is limited under normal refrigeration conditions. The short shelf life of fresh mushrooms is one of the constraints in the distribution and marketing of fresh products. Therefore, in order to maximise the use of mushrooms in the production of high-quality and nutritional food as well as to preserve and ensure that the mushroom can be used for a long period, various mushroom-based products are being developed.

Canned mushrooms have been widely marketed and used in the preparation of mushroom soup, stew, and pizza to replace the use of fresh mushrooms [69–75]. Dried mushrooms have been used in instant soup and sauce preparation [76]. However, the dry form of the edible mushroom has limited uses in food production compared to powdered mushroom which has broad application in food developments. The mushroom powder has great potential as an ingredient in various food products due to its functional characteristics. Mushrooms are recognised as an alternative source of good quality protein and are capable of producing the highest quantity of protein per unit area and time from the worthless agrowastes [77]. Based on a study by Salehi [78], mushrooms contain 22.41% of protein which is higher than the protein in wheat flour. This finding is in line with Wan Rosli et al. [79] and Mendil et al. [80], who reported that the protein content in mushroom is around 25%.

A few studies have been done on supplemented mushroom powdered into food products such as noodles, pasta, rice porridge, as well as bakery products [16, 81–84]. The powder mushroom is mainly being used as a composite flour in bakery production. According to Coelho and Salas Mellado [85], nowadays, there is a lot of attention on the substitution of various flour types for wheat flour to satisfy demands for healthier food. Higher protein content in mushroom powder will develop a better gluten network and produce the right and better elasticity in bakery products as well as in pasta and noodles. The additional amount of mushroom in pasta enhances the antioxidant content [16].

Several studies have been done on the application of mushroom as food additives in food products. Süfer et al. [76] mentioned that the supplemented 5% of *Agaricus bisporus* and *Pleurotus ostreatus* powder in snacks and meatballs gives a promising factor for the production of aromatic and novel foods. The application of mushrooms in meatballs is due to a higher amount of protein and other components such as iron, zinc, selenium, potassium, and vitamin B [86] as well as delicate taste

that leads to the growing demand of red meat. Consuming excessive red meat will lead to serious health problems such as cardiovascular diseases, cancer, and obesity due to its saturated fatty acids. The supplemented mushroom powder is expected to reduce the possibility of having those diseases.

7. The effects of edible mushrooms fortification on food quality

The increase in production and consumption of food products using edible mushrooms is due to their nutritional values as well as medicinal effects. Several studies reported that the addition of powdered mushrooms showed an increase in protein, crude fibre, and ash in various food products. Fortification of powdered mushroom at 6 and 10% showed better results for nutritional values as well as the quality for all food products. The protein content in both bread and muffin supplemented with 10% powdered mushroom showed an increase pattern compared to the control. The increase of protein content in both food products was attributed to the high level of protein in mushroom powder. However, the high level of protein content does not affect the specific volume [87]. This suggests that the protein content in powdered mushrooms is unable to produce/develop the gluten network and improve the viscoelasticity of bread and muffin. According to Ortolan and Steel [88], gluten in protein can be categorised into two, which are vital and nonvital glutes. Nonvital gluten is only used for protein enrichment not for its viscoelastic properties.

The crude fibre content in bread is significantly higher than the control [89]. The higher fibre content in food products is favourable due to its beneficial effect on human health such as protection from constipation, cardiovascular diseases, and obesity [90, 91]. The high fibre content in both bakery products is also one of the main reasons for the lower specific volume in bread and muffins. Increasing fibre content in composite flour generally increases the requirement of water absorption [92]. Indirectly it gives heavier loaf and decreases the bread volume. The addition of high fibre content of flour also shows a negative effect on bread quality due to longer dough development, reduction of gas retention, and limitation of expanding the ability of the dough [93].

The supplemented powdered mushroom is high in protein in bakery products such as bread, cake, muffin, and biscuits [81–83, 90]. The addition of 10% of powdered desert truffles may increase the diameter and thickness of the biscuit. According to Gadallah and Ashoush [82], biscuits that have higher spread ratios are considered most desirable. The additional amount of dessert truffle powdered in biscuits is also proven to have higher antioxidant activities.

The enrichment of protein in pasta and noodles can be achieved by adding shiitake, porcini, and powdered oyster mushroom [16, 84]. The moisture content in noodles supplemented with 10% of mushroom powder shows lower enrichment than the control. According to Foschia et al. [94], the reduction of water is due to the competing of fibre in powdered mushrooms with starch during noodle formation, causing the reduction of starch swelling and water absorption. Besides, the fibre content in noodles with 10% additional powdered mushroom shows significant difference with the control which suggests lower moisture content in noodles.

Most of food products such as bread, cake, biscuits, paratha, rice porridge, and noodles show higher ash content compared to control. Higher ash content means a higher amount of mineral present in food products. The taste, texture, appearance, and stability of food products supplemented with powdered mushrooms also depend on the concentration of mineral [81, 82, 90]. The mushroom powder favoured in rice porridge is due to its meaty flavour. Moreover, they contain high protein, fibre, and minerals. The proximate composition and sensory characteristic of rice porridge

were investigated by Aishah and Wan Rosli [81]. Their result showed that consumer acceptability of rice porridge supplemented with 6% of oyster mushroom powder has a higher score than the control. A similar trend can be seen in paratha bread [81] except for fat content. Besides, the authors reported that there is a huge reduction of fat content in paratha bread supplemented with 6% of oyster mushroom [81].

Chun et al. [95] used shiitake mushroom in pork patty production. This powdered mushroom acts as phosphate in pork patties. Phosphate acts as food additives, which increase the water holding capacity, reduce cooking loss, and improve the texture of food products. Besides, it also protects the aroma and accelerates the formation of cured meat colour [95]. However, in term of sensory characteristics, most of the food products supplemented with powdered mushrooms were less preferred by the panellists in terms of texture, aroma, taste, and overall acceptability. The colour of food products supplemented with mushroom powder shows darker colour, thus affecting the preference of most mushroom-based products [96].

8. Conclusions

Mushrooms are gaining popularity and are widely consumed across the globe by all age groups. Mushrooms are considered to be one of the superfoods due to its high nutrient content, especially protein, dietary fibre, vitamins, and minerals. In addition, mushrooms are also well-known to contain bioactive compounds, such as ergosterol, β -glucans, lentinan, and peroxidase, which possess health functionalities. This claim is backed by various studies showing that mushrooms possessed anti-hypercholesterolaemic, antiviral, anticancer, and antihypertensive activities. Studies have been conducted to investigate the potential of mushrooms in food applications. The findings from these studies showed promising results, whereby the incorporation of mushroom into food products enhances the nutritional values, as well as the physical properties of the food product. Hence, it is not a surprise to know that the food and pharmaceutical industries are using mushrooms or bioactive compounds from mushrooms to develop functional foods.

Conflict of interest

All authors declare there is no conflict of interest in this review.

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