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MINI REVIEW

Beneficial properties of edible mushrooms and their potential utilisation of mushroom waste in food products

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Abstract

In recent years, edible mushroom production has expanded worldwide. However, the amount of mushroom waste produced by the mushroom industries have also increased dramatically. This review explores the nutritional and therapeutic characteristics of edible mushrooms, as well as the possibility of using mushroom trimmings (stem and fruiting body base) as a food ingredient. *Pleurotus sajor-caju* fruiting body base (FBB) flour and underdeveloped mushrooms can be used as an additive in making chicken patties, steamed buns, cookies, and meat nuggets. This ingredient could be used to reduce the use of meat in food products. This can lower lipid levels, reduce cooking loss, while also improving the texture, emulsion stability, and sensory qualities of the product. Mushroom trimmings as part of edible mushroom contains significant nutritional and therapeutic benefits which makes it as ideal food ingredients. Mushroom waste valorisation is in line with the United Nations' Sustainable Development Goals and can contribute to global food security.

1. Introduction

Edible mushrooms are the fleshy and edible fruiting bodies of macrofungal with high nutritional value and unique flavour. Approximately, 10% of global mushroom production has increased over the last three decades. Mushrooms are rich in proteins, lectins, polysaccharides, phenolic and polyphenolic acids, dietary fibre, terpenoids, ergosterols, and volatile chemical compounds. Aside from that, they contain minerals, amino acids, vitamins and other micro and macronutrients which have medicinal properties (Du *et al.,* 2018; Sun *et al.,* 2020). Antiatherogenic, hypoglycemic, antimicrobial, immunomodulator, anticancer, antioxidant, and anti-inflammatory activities of mushroom extracts and secondary metabolites have been reported in several researches (Taofiq *et al.*, 2016).

Edible mushrooms are increasingly consumed globally resulting in increased mushroom stalk and mushroom substrate waste (Wang, 2020). It was reported that up to 20% of the overall yield is wasted during mushroom preparation (Papoutsis *et al.,* 2020). The stems are considered as a by-product of agriculture despite their therapeutic and nutritional potential. Hence the popularity of mushrooms as a delicacy has resulted in increased waste production that contribute to environmental damage (Hassan *et al.,* 2020). In order to achieve the United Nation's Sustainable Development Goals (SDG) 12: Responsible Consumption and Production, it is important to involve the food industries and mushroom growers in valorizing the mushroom waste for sustainable economy. These generated wastes should be converted into valuable materials in an attempt

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to address and comply with SDG12.

Mushrooms are nutritious due to their high content of polyphenols, niacin, polysaccharides, potassium, proteins, selenium, riboflavin, vitamin D and dietary fibres. Therefore, research on their nutritional and therapeutic properties is indeed necessary, which will serve as a starting point towards developing mushrooms and their by-products as functional foods (Leong *et al.,* 2021). This is in line with United Nations' Sustainable Development Goals, (SDG) SDG 2: Zero hunger that promotes food security in mushroom industry and leading towards availability of mushrooms even as functional food rather than fresh counterpart (The 17 Goals - Sustainable Development Goals, 2015). This is necessary due to mushrooms being highly perishable. Mushroom stem base is still considered a waste product to the environment, and its usage is somewhat limited (Mahfuz *et al.,* 2019). Hence mushroom producers need to find a way of making better use of mushroom by-products (Wang, 2020). The utilisation of mushroom waste as a healthy food source is beneficial and can contribute to sustainability.

Although mushrooms are potential functional foods due to their health benefits, however, there are not much research on the nutritional qualities and therapeutic potential of mushrooms. Wang (2020) reported that a large quantity of edible mushrooms is produced annually all around the world and this has resulted in congruently increasing waste based on consumer demand. Hence apart from consuming fresh mushrooms, valorising and utilising mushroom waste is in line with the SDG3: Good health and well-being that promotes healthy lifestyles for all ages (The 17 Goals - Sustainable Development Goals, 2015). The bases or stipes of mushrooms are considered as waste, due to their rough texture. Despite their high nutritional value, mushrooms that have deformed stems and/or caps that do not match consumer standards are considered as mushroom waste (Papoutsis *et al.,* 2020). Hence it is important to find alternative ways for utilising disposal procedures of mushroom trimmings. This review examines the nutritional and therapeutic qualities of edible mushroom species, as well as exploring the possibility for mushroom waste (stem and fruiting body base) to be used as functional components in foods to increase food security and sustainability.

2. Selection of articles

In this systematic review study, the articles were selected from three databases (ScienceDirect, Scopus, and Google Scholar). The literature was conducted from Jan 2021 – October 2022. The search terms used were 'medicinal properties', 'nutrition', and 'mushroom waste' under the (Article title, Abstracts, Keywords). In addition, the term 'mushroom' was used under the 'Search within results' function. About 1808 articles were identified through the database search as indicated in Figure 1.

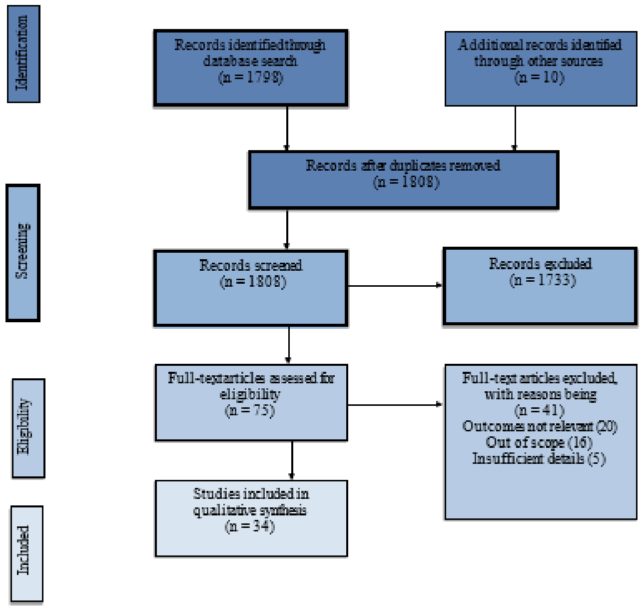

Figure 1. PRISMA flow diagram of article selection.

3. Mushroom background

Mushrooms are macrofungi with unique fruiting body, which can be hypogeous (growing underground), or epigeous (grow above the ground). The term 'mushroom' was derived from the Latin word, mucus (slime) (Sánchez, 2016). Around 20,000 different types of mushrooms have been discovered around the world, with over 3000 of them being safe to consume and 200 of them being wild species. The increase in mushroom production is an environmentally friendly endeavor since it utilizes agro industrial waste as its substrate material. Additionally, they can grow well during rainy season whilst another agricultural crop may suffer due to overly damp environment (Gupta *et al.*, 2018).

Mushroom consumption and production have risen considerably in recent years, with mushroom production increasing by roughly 10% in the last 30 years. In fact, in the Malaysia 12th Plan (RMK-12) and National Agro Food Policy, it is regarded as one of the most significant crops. In recent years, mushroom consumption and production have increased dramatically, with mushroom production increasing by about 10% in the last 30 years. In fact, is it considered as one of the most important crops in the Malaysian 12th Plan (RMK-12) and National Agro Food Policy.

Mushrooms contain minerals, amino acids, vitamins,

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and other micro and macronutrients. According to Du *et al*. (2018), proteins, lectins, polysaccharides, phenolic and polyphenolic acids, dietary fibre, terpenoids, ergosterols and volatile organic compounds are all abundant in mushrooms. Biologically bioactive components with medicinal value can also be found in mushrooms, one of which is the β-D-glucans. In addition, phenolic chemicals, terpenoids, peptides, and steroids are all known chemopreventative substances present in mushrooms. Mushrooms are also high in antioxidants, which is an important protection to fight against free radicals. This can help protect cells from diseases like cancer and heart disease. Mushrooms are high in dietary fibre and low in fat and calories, making them ideal health foods. Leong *et al*. (2021) also mentioned that for decades, they are used in Asian countries to treat diabetes, cardiovascular disease, fester, cerebral arteriosclerosis, hypercholesterolemia, gastrointestinal cancer, liver or heart disease, hyperlipidemia, and stomach ailments.

3.1 Structure, growth, and composition of mushroom

Mushrooms belongs to ascomycetes and basidiomycetes that have a cell cycle, which includes the generation of sexual spores, and growing in two phases, which are reproductive (fruit body) and vegetative (mycelia) (Gupta *et al.*, 2018). Mushroom spores are being catered by the structure called ascus or basidium. Life cycle of mushroom include vegetative growth, reproductive growth, and the production of spores by the mushroom fruit bodies. Mushrooms rely on other organisms for food since they lack the ability to absorb energy from the sun via chlorophyll, which is the most crucial function of plants.

Mycelium is the fungus's living body, comprised of branching hyphae (a small network of threads or filaments) that absorb digestive products, and penetrate the substrate to a certain amount. Under certain conditions, sexually compatible hyphae will join and begin to produce spores. The major process of fungal vegetative development is the re-germination and formation of hyphae from spores produced by the gills. Mushrooms are the largest spore-producing structures, producing millions of spores during their life cycle, from which spores germinate to form mycelium. Furthermore, increased enzyme production and respiration are significantly linked to mycelial growth (Gupta *et al*., 2018).

4. Edible mushroom species

Since 1978, global production of cultivated, edible mushrooms have increased by more than 30 times, from one billion kg in 1978, to 34 billion kg in 2013. Given that the world's population has only risen by around 1.7 times over the same time span, this is a remarkable achievement (Royse *et al.*, 2017). As a result, mushroom consumption rate has increased at a relatively fast rate, especially since 1997, and now exceeds 4.7 kg per year.

Generally, around 85% of the world's mushroom supply comes from five major genera. The first would be *Lentinula* that is the most important genus that accounts for roughly 22% of all cultivated mushrooms in the world. This is followed by *Pleurotus* (19%) (with five or six cultivated species). *Auricularia*, *Agaricus* and *Flammulina* account that accounts for about 17%, 15% and 11% of the total global production respectively (Royse *et al.*, 2017).

4.1 Lentinula edodes

Lentinula edodes (Berk.) Pegler or commonly known as the shiitake mushroom grows on dead wood of numerous deciduous trees, and is widely distributed in Southeast Asia (tropical–subtropical climates) is shown in Figure 2a (Gargano *et al.*, 2017). It was first cultivated in China, 1000 years ago using cut logs. It is now the world's third most grown mushroom that it is commonly grown in artificial substrates made of hardwood sawdust placed in sterilisable polypropylene bags to create “synthetic logs”. In shiitake agriculture, ground corn cobs, peanut shells, wheat straw, coffee husks, sunflower seed hulls, sugarcane bagasse and leaves, cotton stalks, and hazelnut husks have also been used either alone or in conjunction with several other lignocellulosic agro industrial wastes as its substrate.

4.2 Auricularia auricula

Since 600 AD, *Auricularia auricula-judae* (Bull.) Quél. also known as Jew's ear, jelly ear, or wood ear mushroom had been cultivated in China (Figure 2b). Nowadays, they are often cultivated on artificial logs substrates, made of sterilised hardwood sawdust and wheat bran. Moreover, cottonseed shell, wheat, rice straw, sugarcane bagasse, palm oil waste, maize residues, and rapeseed straw are among the other plant by-products that are utilised to produce this mushroom (Gargano *et al*., 2017).

4.3 Agaricus bisporus

The most consumed mushroom in the world is *Agaricus bisporus* (J.E. Lange) Imbach (white or button mushroom or champignon) as shown in Figure 2c. It grows as a saprotroph in humus-rich soils in nature, and is usually cultivated on previously composted and pasteurised chicken/horse manure and cereal straw. An organic (“casing”) sheet consisting of peat moss, is put on top of the substrate after the spawn-run to encourage

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primordia formation. Tea waste, anaerobically digested food waste, defatted pistachio meal, grapeseed meal, spent mushroom compost, and olive mill waste have been trialled as substitutes or supplements for the media (Gargano *et al*., 2017).

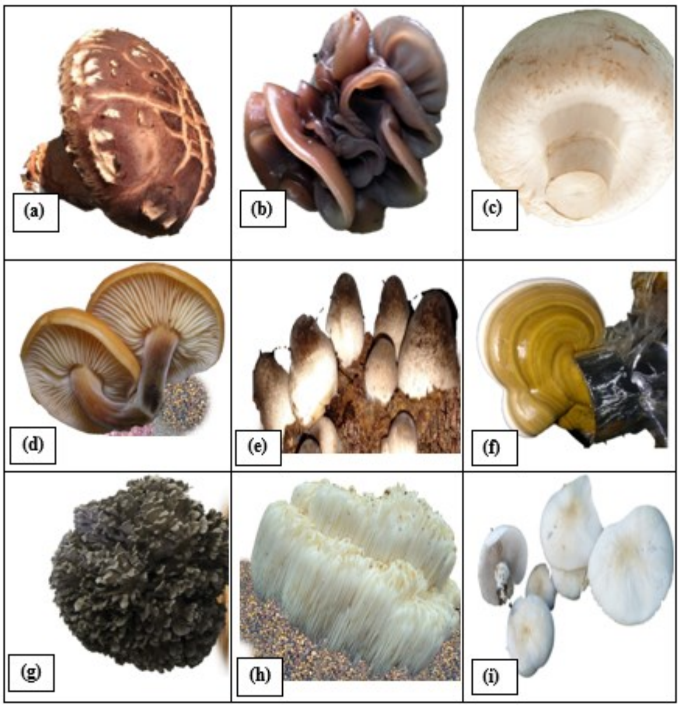

Figure 2. Images of various types of mushroom including (a) shiitake mushroom (*Lentinula edodes*), (b) wood ear mushroom (*Auricularia auricula-judae*), (c) white button mushroom (*Agaricus bisporus*), (d) winter mushroom (*Flammulina velutipes*), (e) paddy straw mushroom (*Volvariella volvacea*), (f) reishi mushroom (Ganoderma *lucidum*), (g) maitake (*Grifola frondosa*), (h) lion's mane (*Hericium erinaceus*), (i) poplar (*Cyclocybe cylindracea*).

4.4 Flammulina velutipes

Winter fungus, enokitake, or golden needle mushroom (*Flammulina velutipes* (Curtis) Singer) usually grows on broadleaved trees in Southeast Asia, Europe, and America (Figure 2d). In the production of *Flammulina velutipes*, sawdust or ground corncobs supplemented with bran are used as substrates, which are stored in polypropylene bottles and sterilised before inoculation. Several other lignocellulosic-rich by-products such as rubber wood sawdust, coffee husk and coffee spent-ground, paddy straw, palm empty fruit bunches and palm-pressed fibre have also been used as cultivation media with good performance (Gargano *et al*., 2017).

4.5 Volvariella volvacea

The paddy straw mushroom, *Volvariella volvacea* (Bull.) Singer is widely cultivated in East Asia and Africa (Figure 2e). It was previously grown on rice straw, but in the early 1970s, significant increases in mushroom yields were reported when using cotton waste as a substrate. Hence, these two waste sources along with banana leaves and pseudo-stems, oil palm waste, wheat straw, sawdust, and sugarcane bagasse have been used after being fermented and pasteurised with varying yields reported (Gargano *et al*., 2017).

4.6 Ganoderma lucidum

For over 40 years, *Ganoderma lucidum* (Curtis) P. Karst. have been grown both outdoors or indoors in substrates prepared in bags or bottles (Figure 2f). When indoors, it is primarily grown on sawdust from broadleaved trees with addition of corn powder, wheat and rice bran, and tea waste as required. Moreover, in commercial or lab-scale development of *Ganoderma* fruiting bodies, some agro-industrial wastes and plant residues have also been used, which included sunflower seed hulls, cotton seed husks, corn cobs, cereal straw and soy waste from tofu processing (Gargano *et al*., 2017).

4.7 Grifola frondosa

Maitake or hen-of-the-woods (*Grifola frondosa* (Dicks.) Gray) naturally grows on hardwood in Asia, Europe, and North America (Figure 2g) (Gargano *et al.*, 2017). Commercial cultivation began in Japan in the early 1980s, and has grown steadily since. Three major methods used are bottle culture bag culture, and outdoor bed culture. The former two methods depend primarily on the use of sawdust from oak, beech and larch trees that have been supplemented with corn, rice, oat and/or wheat bran, soybean cake, or corn meal. However, the yields during indoor cultivation are dependent on high rates of substrate supplementation (ca. 40%), which would be the highest among all mushrooms. Besides, since more than 30% of primordia do not grow into mature fruit bodies, pinning and fructification must be carefully handled.

4.8 Hericium erinaceus

In East Asia, *Hericium erinaceus* (Bull.) Pers. also known as yamabushitake or lion's mane is usually grown on sawdust-based substrates, while corncobs and cottonseed hulls (supplemented wheat bran or with rice) also have been successfully used (Figure 2h). Recently, rice hull and straw, soybean dregs, sugarcane bagasse, sunflower seed hulls, and olive pruning are all found to be suitable for supporting *H. erinaceus* mushroom growth (Gargano *et al*., 2017).

4.9 Cyclocybe cylindracea

Cyclocybe cylindracea (DC.) Vizzini and Angelini (syn. *Agrocybe cylindracea* (DC.) Maire) is a high-quality edible mushroom that is relatively easy to grow (Figure 2i). It can be found on a variety of broadleaved trees, including *Quercus*, *Populus*, *Salix* spp. and *Ulmus*. It is commercially produced in several European and Asian countries, primarily on sawdust-supplemented

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substrates. In addition, several other media, such as rice husks, sunflower and cotton residues, olive-mill by-products, grape marc and others, have also been investigated (Gargano *et al*., 2017).

4.10 Pleurotus spp.

Pleurotus (oyster mushrooms) are regarded as among the most fascinating fungi for various reasons (Masri *et al.*, 2017). First is their ability to flourish in a variety of environments (tropical and subtropical rainforests), as well as their ability to degrade a broad range of lignocellulosic substrates due to their diverse enzymatic activities. Second is the development of a wide range of bioactive molecules with medicinal properties, and its higher nutritional value than other mushrooms. Thirdly their ease of cultivation in solid state fermentation and submerged culture, with higher growth rate than other mushrooms species. Furthermore, *Pleurotus* spp. can colonise and grow fruiting bodies on a wide range of pasteurised substrates, including wood sawdust, cereal straw, sugarcane bagasse, as well as palm oil, olive mill, cotton and coffee wastes, and a variety of other materials (Gargano *et al*., 2017). Mushrooms belonging to the *Pleurotus* spp. differs in morphological features as shown in Figure 3. Additionally oyster mushroom has various members belonging in this genus *Pleurotus* including yellow oyster mushroom (*P. citrinopileatus*) (Figure 3a), abalone mushroom (*P. cystidiosus*) (Figure 3b), pink oyster mushroom (*P. djamor*) (Figure 3c), king oyster mushroom (*P. eryngii*) (Figure 3d), white oyster mushroom (*P. floridanus*) (Figure 3e), pearl oyster mushroom (*P. ostreatus*) (Figure 3f), blue oyster mushroom (*P. ostreatus* var. columbinus) (Figure 3g), Indian oyster mushroom (*P. pulmonarius*) (Figure 3h) and grey oyster mushroom (*P. sajor-caju*) as indicated in Figure 3i which was explained by Samsudin and Abdullah (2019). The members belonging to genus *Pleurotus* are those generally cultivated for human consumption worldwide.

Figure 3. Members of genus *Pleurotus*. (a*)* Yellow oyster mushroom (*P. citrinopileatus*), (b)Abalone mushroom (*P. cystidiosus*), (c) Pink oyster mushroom (*P. djamor*), (d) King oyster mushroom (*P. eryngii*), (e) White oyster mushroom (*P. floridanus*), (f) Pearl oyster mushroom (*P. ostreatus*), (g) Blue oyster mushroom (*P. ostreatus* var. columbinus), (h) Indian oyster mushroom (*P. pulmonarius*), (i) Grey oyster mushroom (*P. sajor-caju*). Source: Samsudin and Abdullah (2019).

5. Nutritional properties of mushroom

Mushrooms have recently become a popular food option, and are regularly considered as a part of everyday diet because of their high concentration of essential nutrients like polyphenols, polysaccharides, niacin, potassium, proteins, dietary fibres, selenium, riboflavin, vitamin B and vitamin D. It has been reported that *Flammulina velutipes* (enoki mushroom), *Agaricus bisporus* (button mushrooms), *Lentinula edodes* (shiitake mushroom), *Grifola frondosa* (maitake mushroom), and other mushrooms are eaten for their nutritional and culinary benefits (Leong *et al*., 2021). On the other hand, mushroom extracts are also combined with fruit juice, soy milk, and frozen yoghurt to create healthy food options.

Mushrooms are the sole source of vitamin D that is not obtained from animals. When exposed to UV light, mushrooms have been found to produce vitamin D_2 in certain situations, and the quantities of vitamin produced exceed the daily vitamin D requirements as reported by Koyyalamudi *et al.* (2009). On a dry weight basis, the mushrooms' fruiting bodies carbohydrate content ranged between 50 and 65%. Monosaccharide, their derivatives, and oligosaccharides are among the sugars found in it. Alcoholic sugars (such as mannitol and trehalose) are also present in the carbohydrates. When subjected to heat, cold, oxidation, and desiccation, trehalose synthesises stress-responsive factors in human cells to maintain cellular integrity. The process involves denaturation of protein, which occurs when proteins are stressed. In addition, mushrooms are high in protein, containing many indispensable amino acids, the most prevalent of which are arginine, aspartic acid, and glutamic acid. Mushrooms also contain two uncommon amino acids which are ornithine (noted for its unusual physiological functions) and γ-amino butyric acid (GABA) (a non-essential amino acid) (Rathore *et al.,* 2017). Furthermore, the combination of dietary fibre (DF) and non-dietary carbohydrates (NDCs) found in mushrooms, such as -glucans, polysaccharides-protein complexes (PSPC), hemicelluloses, mannans, chitin, xylans, and galactose, offers a wide range of health benefits.

5.1 Protein and amino acids in mushroom

In general, edible mushrooms have high protein content, but vary significantly, and are influenced by factors such as species and mushroom growth phase. According to Samsudin and Abdullah (2019), nutritional benefits of mushrooms are strongly contributed by their high protein content. In dry edible mushrooms, the content of free amino acid contributes to its major flavouring properties and is likely to be low between 7.14 and 12.3 mg/g. Free amino acid content is influenced by species, environmental conditions, and maturity stages. Although sulphur-containing amino acids, such as methionine and cysteine, is insufficient in mushrooms, threonine and valine are relatively abundant in edible mushrooms (Gupta *et al.,* 2018). Besides that, aspartic and glutamic acids that give mushrooms their umami flavour, are found at high concentrations in a few types of mushrooms. Gupta *et al.,* 2018 reported that *Pleurotus ostreatus* (black oyster) had the highest concentration of total amino acids (37.99 g/100 g dm) compared to *Pleurotus eryngii* have the lowest concentration of total amino acid (16.36 g/100 g dm).

5.2 Vitamins in mushroom

Mushrooms are a great source of some vitamins, such as vitamin B_2 (riboflavin), vitamin B_3 (niacin) and vitamin B_9 (folate) are found in cultivated mushrooms. Mushrooms have a higher level of vitamin B_2 content compared to vegetables (Gupta *et al.*, 2018). In mushrooms, there are relatively large amounts of folate, and their bioavailability is as high as folic acids. Other than that, trace amounts of vitamins B_{12} and D_2, and a small amount of vitamin C and vitamin B_1, are also present in cultivated mushrooms. Mushrooms are the only food source of vitamin D that is not derived from animal food. When mushrooms are exposed to UV light under certain conditions, they produce vitamin D_2 in quantities far beyond the daily vitamin D requirements. The process of vitamin D_2 generation is catalysed by ultraviolet (UV) radiation from sunlight and involves the conversion of ergosterol (a fungal sterol) to vitamin D_2 through a sequence of photochemical and thermal reactions (Rathore *et al.,* 2017). Ergosterol is abundant in *Agaricus bisporus* mushrooms and when exposed to UV light, it is converted to vitamin D_2. Vitamin D_2 content in an 84g serving of *A. bisporus* (white button mushroom) can be boosted by exposing it to UV-C light after harvest for 5 minutes, resulting in >800% of the daily value. Meanwhile, a combination of UV-B irradiation and hot air drying is observed to boost the vitamin D_2 concentration in shiitake mushrooms (Kamweru and Tindibale, 2016). Table 1 shows the effect of UV irradiation on vitamin D_2 concentration in mushrooms, compiled from various findings.

5.3 Carbohydrate and fibres in mushroom

Edible mushrooms contain high concentrations of oligosaccharides and small amounts of total soluble sugars. The carbohydrate content of edible mushrooms varies from 35% to 70% dry weight, depending on the species (Gupta *et al.,* 2018). Samsudin and Abdullah (2019) stated that carbohydrate is the most abundant element in mushrooms. Mushrooms contain carbohydrates that are both digestive and non-digestible. Digestible carbohydrates include mannitol, glucose, glycogen, and trehalose, while non-digestible carbohydrates include chitin, β-D -glucans, and mannans. The principal components of fungal cell walls are chitin and -glucans, with the latter accounting for most of the total carbohydrates in mushrooms. Although mushrooms are comparable to plants in terms of physiology, they include glycogen and chitin, which are polysaccharides found in animals, rather than starch and cellulose, which are polysaccharides found in plants.

Crude fibre is a type of non-digestible carbohydrate found in mushrooms. Fibre is not hydrolysed in humans because the digestive system lacks the enzymes required to break the glycosidic linkages. Fibre on the other hand, absorbs water and aids defecation as it passes through the digestive tract, emphasising the importance of fibre in human daily nutritional requirements. Several researches have focused on the -glucans found in mushrooms, which are made up of D-glucose monomers linked by -(13) and -(16) linkages. In comparison to β-glucans from oats and barley, β-glucans from mushrooms that have been found to have immune-booster and anti-tumor properties are produced by specific mushroom species such as ganoderan (*Ganodema lucidum*), grifolan (*Grifola fondosa*), lentinan (*Lentinus edodes*), pleuran (*Pleurotus ostreatus*) and schizophylan (*Schizophyllum commune*). Aside from immunomodulatory properties, β-glucans in mushrooms have antibacterial, antiviral, and radioprotective properties.

5.4 Fatty acids in mushroom

In mushrooms, the amount of fatty acid is low at about 2-8%. Polyunsaturated fatty acids account for approximately 75% of total fatty acids, with oleic and linoleic acids being the most significant, whereas the main saturated fatty acid is palmitic acid (Gupta *et al.,* 2018). Linolenic acid has been reported to be the highest fatty acid found in most mushroom being investigated so far compared to palmitic acid, stearic acid, oleic acid and linolenic acid (Sajon *et al.,* 2018). The composition of linoleic acid was highest in *Lentinus edodes* (81.1 g/100 g fresh weight), *Agaricus bisporus* (77.7 g/100 g fresh weight), *Agaricus blazei* (72.42 g/100 g fresh weight), Pleurotus ostreatus (68.9 g/100 g fresh weight) and

Table 1. Influence of UV irradiation on vitamin D2 concentration in mushrooms.

Mushroom	Radiation source	Vitamin D_2 content (μg/g of dry weight)		References
		Control	UV irradiation	
Agaricus bisporus	UV-C	2.20	7.30	Mau *et al.* (1998)
	UV-C	0.07	10.14	Teichmann *et al.* (2007)
	UV-C	7.90	13.40	Guan *et al.* (2016)
	UV-C		23.1	Koyyalamudi *et al.* (2009)
	UV-B	0.01	7.98	Roberts *et al.* (2008)
	UV-B	2.20	12.48	Mau *et al.* (1998)
	UV-B	0.05	4.10	Simon *et al.* (2011)
	UV-B	<5	16.7	Ko *et al.* (2008)
	UV-A	0.07	0.15	Teichmann *et al.* (2007)
Agaricus bitorquis	UV-C	4.01	5.32	Mau *et al.* (1998)
Agaricus blazei	UV-B		22.13	Huang *et al.* (2015)
Agrocybe cylindracea	UV-B	0.95	42.36	Huang *et al.* (2015)
Auricularia polytricha	UV-B		60.29	Huang *et al.* (2015)
Cantharellus tubaeformis	UV-A	1.55	1.57	Teichmann *et al.* (2007)
	UV-C	1.55	14.03	Teichmann *et al.* (2007)
Hypsizigus marmoreus	UV-B	1.62	15.06	Huang *et al.* (2015)
Lentinula edodes	UV-B	2.16	6.58	Mau *et al.* (1998)
	UV-B	0.35	15.10	Huang *et al.* (2015)
	UV-B	2.77	106.4	Ko *et al.* (2008)
Pholiota nameko	UV-B		61.78	Huang *et al.* (2015)
Pleurotus eryngii	UV-B	1.56	28.71	Huang *et al.* (2015)
Pleurotus citrinopileatus	UV-B	3.93	208.65	Huang *et al.* (2015)
Pleurotus ferulae	UV-B	1.65	52.30	Huang *et al.* (2015)
Pleurotus ostreatus	UV-B	0.83	69.00	Huang *et al.* (2015)
	UV-B	1.78	27.89	Banlangsawan and Sanoamuang (2016)
	UV-C	-	48.19	Ruslan *et al.* (2011)
Pleurotus salmoneostramineus	UV-B	2.13	93.29	Huang *et al.* (2015)
Volvariella volvacea	UV-B	3.86	7.58	Mau *et al.* (1998)

Source: Jiang *et al.* (2020).

Pleurotus eryngii (68.8 g/100 g fresh weight) (Sajon *et al.,* 2018). Mushrooms are low in calories, cholesterol-free, and high in fibre and protein. Although mushrooms have a modest lipid content, essential fatty acids make up a large component of the lipid content in most circumstances. Mushroom lipids are primarily mono and polyunsaturated fatty acids, with a low ratio of saturated to unsaturated fatty acids, making them a suitable lipid source (Sande *et al.,* 2019).

6. Medicinal roles of mushroom

Other than being a nutritious food, mushrooms have also been used for medicinal purposes. The use of mushroom as nutraceuticals substances are increasing as it has been reported to have medical and health benefits (Camay, 2016). Medical properties of mushrooms include anticancer, antimicrobial, anti-diabetic, anti-atherosclerotic, anti-hypertensive and neuroprotective effects.

6.1 Cancer disease

Roncero-Ramos and Delgado-Andrade (2017) claimed that cancer has now become one of the leading causes of death worldwide. According to studies from multiple scientific journals, in the prevention and treatment of cancer disease, mushroom polysaccharides may play an important role in the suppression of cancer. Several mushroom polysaccharides activate the innate immune system and exert anticancer action by speeding up the host's defence system. Furthermore, mushroom polysaccharides stimulate the immune system by affecting macrophages, natural killer cells, and T cells. In addition, their cytokine production limit tumour growth. In a double-blind placebo-controlled human clinical trial, shows the ability of *Pleurotus cornucopiae* mushroom to up-regulate the immune response was examined. The data clearly showed that *P. cornucopiae* improved the immune response through Th1 phenotype potentiation via the macrophage-IL-12—IFN- pathway, which leads to cell-mediated immune system activation as seen by up-regulation of natural killer cell activity.

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Following that, regular consumption of *L. edodes* improves human immunity, as indicated by increased cell proliferation and activation, as well as higher levels of secretory immunoglobulin A.

β-glucans are considered the most important compounds for enhancing cellular immunity, and thus exert anti-tumorigenic effects. Grifolan, a β-glucan isolated from *Grifola frondosa* (maitake mushroom) has been shown to have positive benefits in suppression of some cancer, including liver, gastrointestinal, lung, and breast cancers. Grifolan is a macrophage activator that boosts cytokine production, while also increasing the macrophages expression of IL-6, IL-1 and tumor necrosis factor-alpha (TNF-α). However, more research is needed, however, to completely understand the role of grifolan in immune system stimulation and cancer prevention. Furthermore, polysaccharides in shiitake mushroom have a direct antitumor effect against a variety of synergetic tumours and prevent tumour metastasis. The polysaccharides of *Lentinus edodes*, also known as shiitake mushroom, have been used in clinical procedure alongside other traditional cancer treatments. The antiproliferative, anticancer, and immunomodulatory properties of fungal lectins, on the other hand, have gotten a lot of attention. Mushroom lectins inhibit cell proliferation via crosslinking cell surface glycoconjugates or by having an immunomodulatory effect.

6.2 Antimicrobial

Based on study by Piska *et al.* (2017) on antimicrobial activity of mushrooms, water extract from *Pleurotus ostreatus* (Pearl oyster mushroom) mycelium have been shown to have high potency towards some bacteria such as *Escherichia coli* and *Staphylococcus aureus*, as well as fungi such as *Cryptococcus humicola*, *Candida albicans* and *Trichosporon cutaneum*. The active substance against fungi and bacteria in the extract was found to be 3-(2-aminophenyl-1-thio)-3-hydroxypropanoic acid, with MIC of 30 μg mL^{-1} and 20 μg mL^{-1} respectively. Then, ethanolic and methanolic extracts of *P. ostreatus* also have antimicrobial properties. The ethanolic extract was identified to inhibit growth of *Salmonella typhi*, *Staphylococcus aureus*, *Pseudomonas aeruginosa*, *Bacillus atropaeus*, *Bacillus subtilis*, and *Klebsiella pneumonia*. Furthermore, the ethanolic extract also inhibited the growth of *Agrobacterium tumifaciens* and *Candida albicans* at a high potency level. Other than that, *P. ostreatus* methanolic extract also shows antimicrobial activity against gram negative and positive bacteria. The antimicrobial activity has been shown in *P. ostreatus* mushroom can only be achieved at higher concentration of water extracts used with MIC of 30 μg mL^{-1} (Piska *et al.*, 2017).

6.3 Diabetes

Roncero-Ramos and Delgado-Andrade (2017) reported the hypoglycemic activity of mushrooms and their bioactive components. *Pleurotus* species has substantial hypoglycemic potential, in which the oral treatment of *Pleurotus eryngii* (king oyster mushroom) extracts lowered blood glycated hemoglobin and serum glucose levels in alloxan-induced hyperglycemic rats. There have also been researches that showed *Pleurotus citrinopileatus* polysaccharides, *Pleurotus pulmonarius* (Indian oyster mushroom) aqueous extract, or an aqueous extract from *Pleurotus sajor-caju* (grey oyster mushroom) can reduce glucose levels in diabetic rats (Roncero-Ramos and Delgado-Andrade, 2017; Du *et al.*, 2018).

Additionally, administering diabetic rats with 100 and 200 mg/kg body weight of *Hericium erinaceus* aqueous extract for four weeks resulted in a considerable decrease in serum glucose and serum lipid profiles, while a high increase in insulin were recorded (He *et al.*, 2017b). In addition, consuming *Agaricus bisporus* (White button mushroom) powder for three weeks greatly lowered the plasma glucose levels in type 2 diabetes rats (caused by streptozotocin injection) (He *et al.*, 2017b). In addition, *Agaricus blazei* and *Agaricus sylvaticus* are beneficial as it can lower blood glucose, cholesterol, and triglyceride levels while boosting HDL cholesterol to control type 1 diabetes (Niwa *et al.*, 2011). Both *Agaricus blazei* and *Agaricus sylvaticus* mushrooms can protect cells in the Langerhans islets, which secrete insulin (Roncero-Ramos and Delgado-Andrade, 2017).

6.4 Hypercholesterolemia

Roncero-Ramos and Delgado-Andrade (2017) claimed that the high fibre and low-fat content of edible mushrooms can prevent atherosclerosis. Mushrooms and its extract might be regarded as a source of compounds that have hypocholesterolemic activity. This is because they are high in ergosterol derivatives, β-glucans, eritadenine, and inhibitors of the enzyme HMG-CoA reductase (the main enzyme in endogenous cholesterol biosynthesis). It has been shown that eritadenine inhibits a main enzyme in phospholipid metabolism, which is S-adenosylhomocysteine hydrolase (SAHH) that can lower cholesterol and triacylglycerol amounts in rats (He *et al.*, 2017b). Hypercholesterolemia in mice caused by a high fat diet can be reduced greatly via supplementation of eritadenine and *L. edodes* powder (Nisar *et al.*, 2017).

6.5 Hypertension

Angiotensin-converting enzyme (ACE) is a central component of the renin–angiotensin system. ACE causes blood vessels to narrow, which indirectly raises the blood pressure. Mushrooms such as *H. erinaceus, G. frondosa, A. bisporus, Hypsizygus marmoreus,* and genus *Pleurotus* have been used to treat hypertension. Mushroom extracts used as an alternative to synthetic antihypertensive drugs. Hot water extracts of mushrooms contain active antihypertensive constituents that include peptides, D-glucose, D-galactose, D-mannitol, D-mannose, triterpenes, and potassium. Through a variety of mechanisms, these different components can work together to prevent and treat hypertension, by inhibition of the renin–angiotensin–aldosterone system through interaction at the ACE enzyme's active sites. *H. marmoreus* water-extract has been shown to contain an ACE inhibitor and exhibited antihypertensive effect on a spontaneously hypertensive rat (Kang *et al.*, 2013).

6.6 Neurodegenerative disease

According to Lee *et al.* (2019), neurodegenerative diseases are a disorder that occurs by the selective loss of neurons, which include Parkinson's disease, Huntington's disease, Alzheimer's disease, and amyotrophic lateral sclerosis. Roncero-Ramos and Delgado-Andrade (2017) stated that *Ganoderma lucidum, G. frondosa, Sarcodon scabrosus* and *Hericium erinaceus* mushrooms have been shown to have nerves and brain-related properties. *H. erinaceus* (Lion's Mane mushroom) has been tested the most for its neurohealth benefits, in which two types of its functions on the nervous system have been established. *H. erinaceus* can control the growth and development of neurons and other supporting structures. *H. erinaceus* bioactive compounds was noted to activate nerve growth factor (NGF) formation in 13121N1 human astrocytoma cells (Mori *et al.*, 2008). NGF is known to play a key role in nervous system regulation. *H. erinaceus* also has been linked to the treatment and/or prevention of neurodegenerative diseases like dementia, Alzheimer's disease, cognitive dysfunction, and depression, which are linked with a progressive loss of neuronal function (Mori *et al.*, 2008).

Endoplasmic reticulum stress and mitochondria stress can cause neuronal death. Mitochondrial stress is caused by oxidative burden, and is linked to neuroinflammation, which have negative effects. It has been discovered that treatment using *H. erinaceus* can greatly increase a type of protein known as lipoxin A4, which has anti-inflammatory properties in brain areas (Lee *et al.,* 2019). In addition, it also increased the expression of cytoprotective proteins like heme oxygenase-1 (HO-1), thioredoxin (TRX) and heat shock protein 70 (Hsp70). Components in *H. erinaceus* can also protect the neuron from endoplasmic reticulum stress, which is caused by sustained Ca^{2+} depletion.

6.7 Other bioactive properties

Mushrooms and its components provide a number of other health benefits. Mushroom aqueous extracts have been found to be hepatoprotectors, with antioxidant activity responsible for protecting the liver. Endo-polysaccharides from *H. erinaceus* have been found to protect hepatic tissues from paracetamol-induced harm, whereas an aqueous extract of *A. blazei* (also known as "Himematsutake" in Japan) protects hepatic tissue from paracetamol-induced injury (Soares *et al.*, 2013). Aside from that, mushrooms and their extracts may be effective in the treatment of allergies by boosting the immune system. Ethanolic extracts of edible mushrooms such *H. marmoreus, Flammulina velutipes, Pholiota nameko,* and *Pholiota eryngii* were found to have significant antiallergic effects in mice (oxazolone-induced type IV allergy) (Sano *et al.*, 2002). Antibacterial, antifungal, and antiviral activities in a variety of mushrooms were have been reported. Although the antiviral effects of mushrooms do not appear to be linked to viral adsorption or virucidal effects (i.e., they do not kill the virus), studies have shown that they decrease virus replication in the early stages. Mushrooms have also been linked to the treatment of leukaemia, DNA damage, wound healing, rheumatoid arthritis, and eye health in some studies (Roncero-Ramos & Delgado-Andrade 2017). Reis *et al.* (2017) mentioned that mushrooms are now being used as natural bio-control agents in plant defense (as insecticides, fungicides and bactericides) and cosmetics (due to their film forming capability, antioxidant, anti-allergic or antibacterial activities, stimulation of collagen activity). They are also consumed in a variety of ways, such as foods, dietary supplements and medicines (often referred to as "mushroom pharmaceuticals").

7. Potential utilisation of mushroom waste

According to Mahfuz *et al*. (2019) increased consumer demand has led to an increase in mushroom stem base production, which is currently regarded as a waste material. Papoutsis *et al*. (2020) reported that during mushroom processing, a significant amount of waste was produced that accounted for up to 20% of total production. Mushroom waste consists primarily of mushrooms that have mis-shapen caps and/or stalks and do not meet retailer requirements and governmental standards. These mushroom by-products have good nutritive values (Hassan *et al.*, 2020).

Mushroom waste can be used to make vitamin D_2-enriched extracts that could be used as dietary supplements in the pharmaceutical industry or as an additional ingredient in foods in the food industry (Papoutsis *et al*., 2020). Wan-Mohtar *et al.* (2018) reported that for economic, environmental and

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sustainability reasons, there is a collective demand to use agricultural food by-products. The agricultural food industry relies heavily on edible mushrooms. Mushroom waste can be used to manufacture vitamin D and chitosan.

Mushroom stalk bases are produced as a waste product during mushroom harvesting (Bilbao-Sainz *et al.,* 2017). Based on studies by Wang (2020), every year, a large number of edible mushrooms are harvested all over the world. The amount of unwanted mushroom parts (mushroom stalk waste), as well as spent mushroom substrate, is rising dramatically every year (Figure 4). While large-scale mushroom cultivation has significant economic benefits, it also generates a lot of mushroom waste. The bases or stipes of mushrooms are regarded as waste materials during the production due to their rough texture.

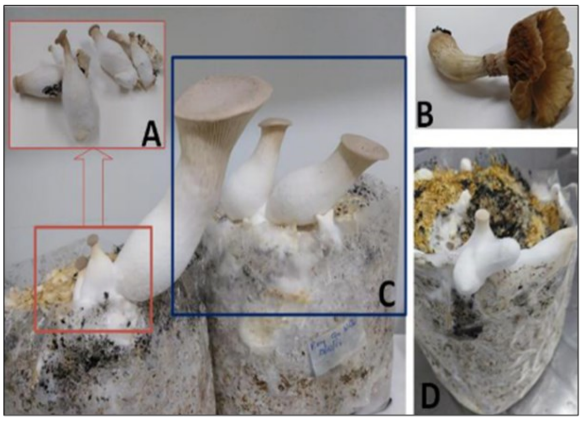

Figure 4. Mushroom by-products. Images showing (A, B) stipes and mushrooms that do not meet commercial caliber, shape, or size requirements (5–20% of the production weight); (C) by-products (surplus production: ≤ 5%); (D) spent mushroom substrate (>20% of the production weight). Source: Antunes *et al.* (2020).

Every day, a massive amount of mushroom waste collects in the open environment, posing a threat to the ecosystem. Every year, mushroom waste affects mushroom growers' profit margins significantly. Given the continual rise in raw material prices, mushroom growers are faced with the task of figuring out how to make better use of the by-products of mushroom cultivation while lowering production costs. Oyster mushroom processing generates a lot of waste, in whereby 1 kg of commercial oyster mushroom produces 165–502 g of mushroom stalk waste. The raw polysaccharide derived from the oyster mushroom stalk waste is utilised as a fish feed supplement because it is inexpensive, has high β-glucan content and can help fish cope with pH-induced stress, allowing them to grow faster under stressful conditions (Wang, 2020).

7.1 Fruiting body base flour from mushroom waste for developing chicken patty

Antioxidants include phenolic substances, flavonoids, ascorbic acid, glycosides, tocopherols, polysaccharides, ergothioneine, and carotenoids are abundant in oyster mushrooms (Bach *et al.*, 2017). Antioxidant compounds protect cells from damage by neutralising free radical molecules. A cap, stem and fruiting body base (FBB) make up *Pleurotus sajor-caju*. However, the FBB are always discarded, and only the cap and stem are collected for commercial use. Despite this, investigations have revealed that FBB flour from the *P. sajor-caju* strain QDR has a high quantity of protein (5.57%) and has antioxidant properties (Wan-Mohtar *et al.*, 2020). Antioxidants can be extracted from *P. sajor-caju* using a variety of pretreatment procedures. Physical and chemical treatments are used to either boost antioxidant activity or retain firmness, colour and weight after harvest. It was reported that cabinet oven drying of *P. sajor-caju* resulted in 15.26% of crude protein, 0.58% crude fat and 64.75% total carbohydrate, which was significantly higher compared to other drying techniques using microwave oven and vacuum oven (Siti-Nuramira *et al.*, 2022). The mushroom is abundant in protein, vitamins and minerals while being low in calories, fat and sodium. Therefore, protein derivatives derived from mushrooms have been utilised in meat products as alternative protein sources in diets.

Based on studies by Wan-Mohtar *et al.* (2020), the inclusion of FBB flour affected the mushroom patties' texture characteristics. The hardness of commercially available chicken patties ranged from 8003.25 to 19,038.15 N. The hardness ($P < 0.05$) of 20% and 30% FBBF-fortified chicken patties ranged from 26,544.06 to 36,634.72 N. However, the hardness of 10% FBBF-fortified patties ranged between 9533.24 to 9610.50 N. Hence, only 10% FBBF-fortified patties are similar to the control, and fall within the recommended range in terms of hardness. Following that, the FBBF-fortified patties' chewiness ranged from 1275.07 to 8432.92 J, whereas springiness (m) ranged from 0.384 to 0.478 m and cohesiveness vary from 0.347 to 0.481, respectively. The chewiness, springiness, and cohesiveness of the FBBF-fortified patties increased significantly as the concentration of FBBF increases. The textural qualities of commercially available chicken patties ranged from 650.78 to 1275.78 J for chewiness, 0.141 to 0.443 m for springiness, and 0.223 to 0.371 for cohesiveness. According to the findings, only 10% FBBF-fortified chicken patties fall within the recommended range of textural qualities. In addition, 56.7% amylose and 43.3% amylopectin are found in the starch of oyster mushrooms. The inclusion of FBBF may increase the levels of amylose, which is related to hardness and

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chewiness, and amylopectin, which is associated to cohesiveness and springiness, resulting in a harder chicken patty.

The permitted lightness (L*), redness (a*) and yellowness (b*) values for commercial chicken patties were reported to be between 48.21 to 66.11, 2.55 to 9.07 and 21.56 to 31.24, respectively. The L* values for FBBF-fortified chicken patties (10% and 20%) ranged from 49.12 to 60.45, which are considerably ($P<0.05$) lower than the control patty (64.45). The browning impact of frying, as well as the greyish colour of FBBF, could explain the darker appearance of the FBBF-fortified chicken patties. The caramelisation of polysaccharides in FBBF during the cooking process is shown to cause the browning of chicken patties (Wan-Mohtar *et al.*, 2020). The b* values ($P > 0.05$) of the chicken patties were not affected by the addition of 10% (30.16) and 20% (30.70) of FBBF. However, 30% FBBF -fortified chicken patty exhibited a significantly lower b* value (28.72) than control but significantly different ($P<0.05$) than 20% FBBF-fortified chicken patties. The a* value of the FBBF-fortified chicken patties ranged from 9.05 to 14.38 ($P < 0.05$) which was significantly higher compared to the control patties (7.69), which could be attributed to the browning of the patties' surface. Hence, 10% FBBF-fortified chicken patties were within the range of commercial patties in terms of a* value and are considered acceptable. The addition of FBBF to chicken patties at 10% and 20% ($P>0.05$) did not influence the yellowness (b*), but did decrease significantly the lightness (L*) and enhance the redness (a*). Only 10% of the FBBF-fortified chicken patties were similar to the commercial ones in terms of colour profile, which is regarded as acceptable.

The sensory attributes for the FBBF-fortified chicken patties were evaluated in terms of appearance, colour, aroma, texture, taste, after taste and overall acceptability. The 10% FBBF-fortified chicken patty received the significantly highest colour and appearance score of 7.06 and 7.00, respectively. The control patties were too pale, whereas the 20% and 30% FBBF-substituted chicken patties were excessively dark. In addition, the 10% FBBF-fortified chicken patty (5.86) was rated less than the control patties (6.73) in terms of aroma and texture. The 20% and 30% FBBF-fortified chicken patties, on the other hand, rated the lowest due to their hard texture and overpowering mushroom odour. The taste and aftertaste of the 10% FBBF-fortified chicken patty are both approved by the panel (5.20 and 5.29, respectively). The natural mushroom umami flavour of FBBF is likely to have influenced the overall liking of the 10% FBBF-fortified chicken patty flavour, making it more appealing to the panelists.

7.2 Fruiting body base flour from mushroom waste in the development of potential steamed bun and cookies

FBB flour has been used to develop baked products. Wan-Mohtar *et al.* (2018) formulated cookies and steamed buns made primarily of FBB flour. Mushroom flour can be used as a healthy alternative use in steamed buns and cookies.

Oyster mushroom is known to be high in antioxidants in all parts of the mushroom. Phenolic compounds are the most powerful antioxidants found in mushrooms. Imbalances between free radicals and antioxidants will cause oxidative damage, and aging is the most frequent form of oxidative damage in human body. Antioxidant compounds protect cells from damage by neutralising free radical molecules, lowering the occurrence of diseases for humans such as cancer, cardiovascular disease, and diabetes mellitus (Wan-Mohtar *et al.,* 2018). Floured fruiting body base of *P. sajor-caju* has been used to make functional steamed buns and cookies (Figure 5).

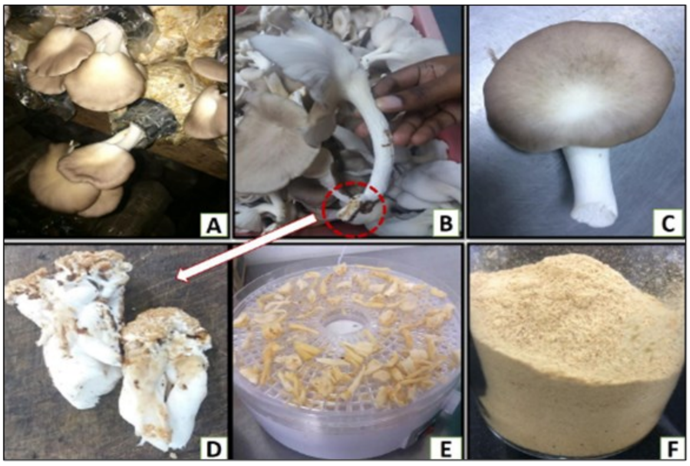

Figure 5. Fruiting body base (FBB) harvesting process flow from commercialised *Pleurotus sajor-caju*. (A) first week of harvesting, (B) entire fruiting body (cap, gills, stem, and base), (C) fruiting body (cap and stem), (D) raw fruiting body base (FBB), (E) dried fruiting body base (FBB), (F) floured fruiting body base (FFBB). Source: Wan-Mohtar *et al.* (2018).

The proximate composition of the raw fruiting body base (RFBB) and floured fruiting body base (FFBB) of *P. sajor-caju* strain QDR. The moisture content of FFBB (8.93±0.15) was significantly lower than RFBB (84.4±3.08). FFBB had more minerals compared to RFBB, since the ash content in FFBB was higher (5.72±0.04) than RFBB (0.76±0.06). FFBB also had showed a higher (5.57±0.2) amount of protein compared to RFBB (1.54±0.17). Protein content in FFBB is higher as it is mixed with wheat flour. β-glucan is a type of fibre found in abundance in mushrooms that has been examined extensively for its anti-cancer potential. The carbohydrate content of FFBB (71.2±1.38) was significantly higher compared to RFBB (7.57±3.51).

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The antioxidant properties of FFBB polysaccharide extract of *P. sajor-caju* strain QDR and their comparison with results from different mushroom species (Wan-Mohtar *et al.,* 2018). The phenolic content of 250 mg/mL FFBBP extract (1.8±0.09 mg GAE/g) was significantly lower than *P. ostreatus* 32783 (11.36 mg GAE/g). Results showed that the reducing power of 250 mg/mL of FFBBP extract (1.74±0.01 mM Fe(II)/ g) was higher compared to *P. ostreatus* 32783 (0.001 mM Fe(II)/g). The FFBBP extract concentration also had a significantly higher free radical scavenging activity (IC_{50} = 25.08 mg/mL) compared to *P. ostreatus* 32783 (IC_{50} = 317.09 mg/ml). Other *Pleurotus* spp. such as *P. pulmonarius* CP-799 (IC_{50} = 0.0037 mg/mL), *P. levis* CP-30 (IC_{50} = 0.005 mg/mL) and *P. tuber-regium* CP-182 (IC_{50} = 0.005 mg/mL), have higher free scavenging activity because they utilise the fruiting body (cap and stem), rather than the fruiting body base alone.

The sensory analysis of both steamed buns and cookies are conducted by using a nine-point hedonic scale. The consumer acceptability of steamed buns and cookies prepared with different FFBB percentages had been analysed previously (Wan-Mohtar *et al.,* 2018). For the steamed buns, as the content of FFBB increased, the acceptability score decreased in terms of appearance. The 20% FFBB liking score for colour was significantly higher than the 10% and 30% FFBB samples. FFBB had darken throughout the steaming process and as a result the bun containing 30% FFBB bun was not preferred by the panellist. In terms of aroma, the control and 10% FFBB buns scored the same, followed by 20% FFBB and the lowest is 30% FFBB because of the strong smell of the mushroom. For the texture attribute, 10% FFBB has the highest texture score, followed by control, 20% FFBB and 30% FFBB. Because mushroom flour contains a lot of crude fibre, the texture scores for the four levels are not too different from each other. The bitter taste of mushroom flour may have contributed to the lower scores of 20% and 30% FFBB.

The liking score for appearance, aroma, texture, colour and aftertaste decreased for cookies as the level of FFBB incorporated increased. In terms of taste, the highest liking score was 10% FFBB, followed by control, and the lowest was 20% FFBB. This shows that the taste of 10% FFBB is acceptable. For overall acceptance, 10% FFBB score that is close to the control, and 20% FFBB score is notably different from the control.

Liking of steamed bun and cookies containing 10% FFBB was similar to the control sample. However, 20% and 30% FFBB samples were significantly the lowest in terms of attributes compared to 10% FBB and control samples.

7.3 Application of mushroom wastes as functional ingredients in goat meat nuggets

Dietary fibre and other bioactive elements such as minerals, vitamins, and polyphenols are abundant in plant-based waste products. Plant-based waste materials are becoming increasingly popular as an ingredient in meat products. Mushroom powder extracts have good nutritional qualities, including a healthy lipid profile, a low-calorie density, and high levels of phenolic, fibre, and protein. This makes them ideal for usage as functional food ingredients in a variety of foods. Enoki mushrooms (*Flammulina velutipes*) are well-known for their high nutritional value and appealing flavor. It is a potential functional ingredient in goat meat nuggets (Banerjee *et al.,* 2020).

Banerjee *et al.* (2020) investigated the use of dried enoki mushroom stem waste (MSW) as a functional ingredient in meat products. The authors formulated control (0% MSW), T2 (2.0% MSW), T4 (4.0% MSW) and T6 (6.0% MSW) goat meat nuggets.

Previously, it was found that moisture (12.9±0.3%), protein (13.5±0.7%) and ash content (8.24±0.05%) of enoki MSW powder was high. The fat content of MSW powder was low (1.47±0.04%). Total dietary fibre of MSW powder was high (32.3±0.9%), which included the soluble dietary powder (17.3±2.1%) and insoluble dietary fibre (15.1±2.7%) components. Furthermore, because of their propensity to form gel networks that hold water and regulate texture, these dietary fibres may aid in the development of low-calorie, low-fat, and high-fibre meat products.

Enoki mushroom extracts are a rich source of natural antioxidants. Enoki mushroom stem extract was found to have 6.3 mg GAE/g dry weight of total phenolic content. The free radical scavenging activity using DPPH and FRAP were 84.2% and 60.1%, respectively. The ability to chelate ferrous ion was found to be 41.3%. There was influence of enoki MSW on the physicochemical, texture, and colour characteristics of goat meat nuggets. As the content of MSW powder added increased, the pH of the emulsion increased as well.

Increasing MSW powder addition also improves emulsion stability (%) of meat nuggets. As enoki mushroom contained a high amount of total dietary fibre, it improved the oil absorption and water retention qualities of the beef emulsion, which explained improved emulsion stability and cooking loss. Additionally, the decrease in expressible water (%) indicated that the water holding ability of goat meat nuggets improved. With increasing enoki MSW powder, the total phenolic content increased. The addition of MSW increased ash and dietary fibre content significantly compared to control samples.

Textural properties of the nuggets were also influenced by MSW powder addition into the nugget formulation. The addition of MSW powder only reduced the hardness, springiness, cohesiveness and gumminess of the meat nuggets slightly, but there was a significant reduction in the chewiness of the nuggets with increasing MSW powder addition. Gelation of the meat's myofibrillar proteins and also the biopolymer networks generated by the dietary fibres from the plant, are responsible for the textural qualities of cooked meat products that contain plant components.

Consumers are influenced by the colour of food products. In terms of colour, the amount of enoki MSW powder added influenced the lightness (L*) of the nugget significantly. There was a significant increase in the lightness of nuggets containing 6.0% MSW. The redness (a*) of the nugget, on the other hand, has decreased, while the yellowness (b*) did not change significantly. The redness (a*) of nuggets made with 6.0% MSW is greatly reduced compared to control.

The sensory characteristic of the goat meat nuggets includes appearance, texture, flavour, juiciness and overall acceptability (Banerjee *et al.,* 2020). The sensory acceptance was not influenced by the level of enoki MSW powder used. Hence, enoki mushroom may be advantageous in food applications, as it has a mild and delicate flavour. Additionally, the white colour of enoki mushrooms may be advantageous since it does not change the overall hue of the finished meat product but does reduce its lightness slightly.

The primary peroxide value (PV) and secondary thiobarbituric acid reactive substances (TBARS) lipid oxidation products of goat meat nuggets were measured up to 9 days of storage to examine the effect of MSW powder addition on the oxidative stability. The PV and TBARS of meat nuggets with 2.0%, 4.0%, and 6.0% MSW powder were lower than control. The PV value of control meat nuggets increased to 1.21 meqO_2/kg on day nine, from an initial value of 0.64 meqO_2/kg. After six days of storage, a significant decrease in the PV value, indicating that the hydroperoxides generated decomposed to form secondary lipid oxidation products. Over the nine days of storage, the TBARS value for both control and treated meat nuggets increased over time. The TBARS value of the control increased from 0.32 mg MDA/kg to 0.85 mg MDA/kg, while the TBARS value of meat nuggets treated with 2.0%, 4.0% and 6.0% mushroom only increased from 0.32 mg MDA/kg to 0.58 mg MDA/kg. Hence mushroom stem waste addition into goat meat nuggets can reduce lipid oxidation during storage. Enoki mushroom extracts are efficient antioxidants that can inhibit lipid peroxidation when added to goat meat nuggets during refrigerated storage for up to nine days. Up to 4.0% enoki mushroom stem waste addition was acceptable to create nutritionally improved and healthier meat nuggets.

8. Conclusion

Edible mushrooms offer nutritional and therapeutic properties. Important components in edible mushrooms include polyphenols, niacin, polysaccharides, potassium, selenium, riboflavin, and dietary fibres. Mushrooms are high in protein and include a variety of essential amino acids. Mushrooms were also a good source of vitamin B, and the only non-animal source of vitamin D. Mushrooms like *Pleurotus* sp., *G. frondosa*, *A. bisporus*, *Hypsizygus marmoreus*, and *H. erinaceus* can be used to treat hypertension. Mushrooms are also antimicrobial and can be used to treat hypercholesterolemia and neurodegenerative diseases. With increase in mushroom demand, increasing amount of mushroom waste being generated. Mushroom waste includes stems, fruiting body base and mushrooms that did not meet the requisite standards that have high nutritional value. To reduce the environmental impact of mushroom waste, there is increasing interest in converting mushroom waste into functional food ingredient. Mushroom waste has been incorporated in food products, like meat as patties, buns, cookies, and nuggets. More research is needed to better understand how mushrooms and mushroom waste products that have beneficial nutritional and health promoting properties can be used to develop functional foods, particularly in the area of mushroom-based novel food product creation.

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