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REVIEW

Drying treatments of oyster (*Pleurotus* spp.) and shiitake (*Lentinula edodes*) mushrooms: a review

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Abstract

Oyster (*Pleurotus* spp.) and shiitake (*Lentinula edodes*) mushroom, a fungus that is increasingly being recognised as a source of food with various benefits for human health. Mushrooms are highly perishable. Drying is a common method used after harvest in the processing of fresh food for increasing the shelf life. Among these different drying methods, freeze drying is the best technique to use in many types of research as it can maintain most of the nutrition in the mushroom. However, the combination of two or more drying methods will produce better results. This review paper closes with an overview discussion on the production of new products substituting with oyster mushrooms and shiitake mushrooms that are more nutritious and can provide many benefits to human health and improve the shelf life of mushrooms by different methods of drying. Food products substituted with mushroom powder result in a decrease in carbohydrate and moisture content and an increase in protein, fibre, ash, and other micronutrients.

1. Introduction

The mushroom industry is growing as one of the sources of food. Over the last three decades, global trade in mushrooms has shown an important upward trend, particularly for fresh and dried mushrooms (Amin *et al*., 2014). Information to the Food and Agriculture Organization, around 10.2 million tons of mushrooms and truffles were made worldwide (FAO, 2017). According to FAO (2015), Asian countries manufacture more than 74.64% of the world's mushroom markets followed by Europe (19.63%), the United States of America (4.92%), Oceania (0.60%) and Africa (0.21%) in 2014 as shown in Figure 1. Malaysia is also included in this industry. The import value increased from RM9.71 million in 2005 to RM18.18 million in 2012.

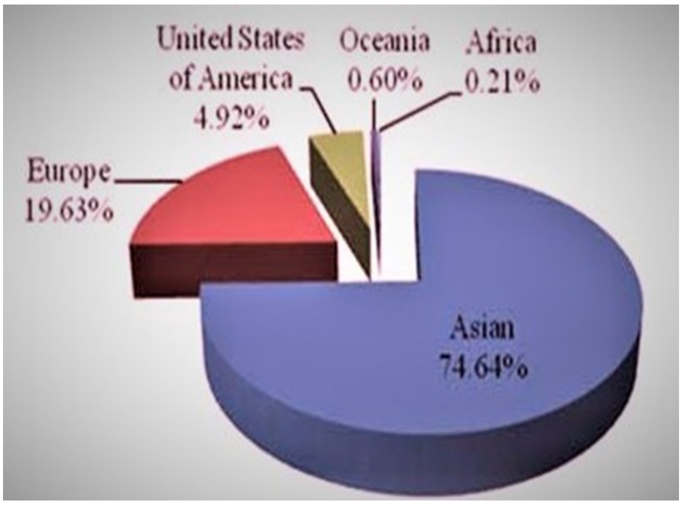

Figure 1. World mushroom production in 2014 (FAO, 2015).

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Production of mushrooms in Malaysia can be increased to meet domestic market demand. The weather in the Malaysian country is ideal for cultivating a diverse variation of low-cost speciality mushrooms, and the growing of the species is essential to raise both the quantity and quality of domestic production in the future. In general, there are more than 2,000 edible fleshy mushroom species, with fewer than 100 cultivated worldwide in more than 60 countries. Malaysia is a mushroom producer, and for the local and export markets around 1,000 tons of mushrooms are grown annually (Amin *et al*., 2014).

Oyster mushrooms are a kind of fungus that is edible. This is one of the most eaten mushrooms worldwide. From their oyster-shaped cap and very short stem, they get their name. The colour of oyster mushrooms is like crude oysters. Usually, oyster mushrooms are a light grey or greyish-brown colour. Besides, the scientific name of the shiitake mushroom is *Lentinus edodes*, which is one of the most widely grown and common edible mushrooms in the world. It was originally grown in East Asian countries but is now also commonly grown in Europe and the United States (Van and Thu, 2018).

Today, under-nutrition problems, including protein-energy malnutrition and deficiency of micronutrients, particularly iron, vitamin A, iodine, and folic acid, continue to have detrimental effects on vulnerable communities in many nations around the world undergoing nutritional transition. Malnutrition refers to a pathological state resulting from one or more essential nutrients being relatively or absolutely deficient or excessive. It can cover four aspects of undernourishment, overnutrition, imbalance, and the specific deficiency (Chen *et al*., 2012). Thus, consuming mushrooms in the daily diet may help to overcome these problems. Mushrooms are fungi that contain high levels of protein, carbohydrates, multivitamins, and healthy minerals and a rich source of folic acid, vitamins and minerals that are suitable for nutraceutical, pharmaceutical and cosmetic products (Amin *et al*., 2014). Mushrooms are highly perishable. Thus, it must be stored in the form of dried, marinated, pulverized into powder, or smoothed into a paste to extend the shelf life. Most of the mushrooms had been used as a wheat flour substitute. The production of new products substituted with oyster mushrooms and shiitake mushrooms may be more nutritious and can provide many benefits to human health. Besides, many new innovative products can be produced proportional to the increment of technology. The drying method of mushrooms is not only to prolong their storage life, but it can also increase their nutritional value and improve their functional features (Giri and Prasad, 2013). To ensure long-term supply by reducing water activity to microbial protection standards, mushroom drying is a typical post-harvest technique. The objectives of the study are to understand the types of substrates used for drying treatment and the nutritional value of oyster and shiitake mushroom-based products.

2. Nutritional value of mushroom

The production of new products substituted with oyster mushrooms and shiitake mushrooms will produce more nutrition and provide many benefits to human health. In general, food products substituted with mushroom powder resulted in a decrease in carbohydrate and moisture content; and an increase in protein, fibre, ash, and other micronutrients.

2.1. Different parts of mushroom nutritional composition

In general, the different part of the mushroom has different proximate value. Barroso *et al*. (2020) had experimented Shimeji and brown Paris caps of mushrooms that show high protein values and similar lipid content in mushrooms. Interestingly, mushroom fat could be utilized for human nutrition because of low SFA/UFA ratios (~0.2–0.4) with the similar level of vegetal oils (Boukid *et al*., 2022). Mushroom moisture and ash vary by mushroom type, but the white Paris mushroom has recorded the highest ash value in caps and stems. The composition of amino acids can become an indicator of the dietary value of food. Free amino acids (FAA) are the principal components of functionally essential compounds found in mushrooms. The non-volatile compounds, such as free amino acids and soluble sugars, can provide the most typical mushroom taste. Information from Dospatliev *et al*. (2019), who conducted a study to identify the FAA compositions of *Morchella esculenta* harvested from the Batak mountain shows the total FAA contents of the cap, was 26.17 mg kg^{-1} and that of the stem 42.75 mg kg^{-1}. The essential to non-essential amino acid ratios of the cap and the stem were 0.18 and 0.33, respectively (Dospatliev *et al*., 2019). This means that different parts of mushrooms have a different composition of FAAs.

3. Treatment of mushroom

Mushrooms must undergo a few treatments to extend their shelf life. The mushroom drying method used during the mushroom processing can help to produce high-quality. Thermal drying uses heat application onto food materials to remove water presence by evaporation which eventually improves shelf life with a reduced water activity (Calín-Sánchez *et al*., 2020). Meanwhile, the non-thermal drying technique does not utilise heat for drying purposes, however, changes the temperatures within the food materials (Onwude *et al*., 2017).

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3.1 Drying methods

The drying of food is one of the complicated phenomena that determines its drying properties (Ramarathinam *et al.*, 2022). Fresh mushrooms are perishable due to their high-water activity and have a short shelf life. Drying is a common method used after harvest in the processing of fresh food. Not only prolong their storage life but can also increase their nutritional value and improve their functional features (Giri and Prasad, 2013). To ensure long-term supply by reducing water activity to microbial protection standards, mushroom drying is a typical post-harvest technique. Dried fungi have a distinctive texture, taste and nutritional value and are used in several food formulations. Reasonable mushroom drying techniques may improve the unique taste of mushrooms, retain colour, establish a better texture, and can be completely rehydrated in water (Argyropoulos *et al.*, 2011). In the food industry, different drying methods are used to make mushroom powder and each drying method has its own specific effect on the microstructural, physical, chemical, and functional properties of mushrooms. Figure 2 illustrates the effects of various drying methods including Vacuum, microwave vacuum, microwave and hot air on the microstructure of dried shiitake mushrooms (Tian *et al.*, 2016). The dried mushroom powder can also partially replace wheat flour by adding to the functional baked goods the protein and fibre content, as well as other nutrients. According to Bashir *et al*. (2020), all the drying methods resulted in a steep decline in the moisture content of oyster mushrooms.

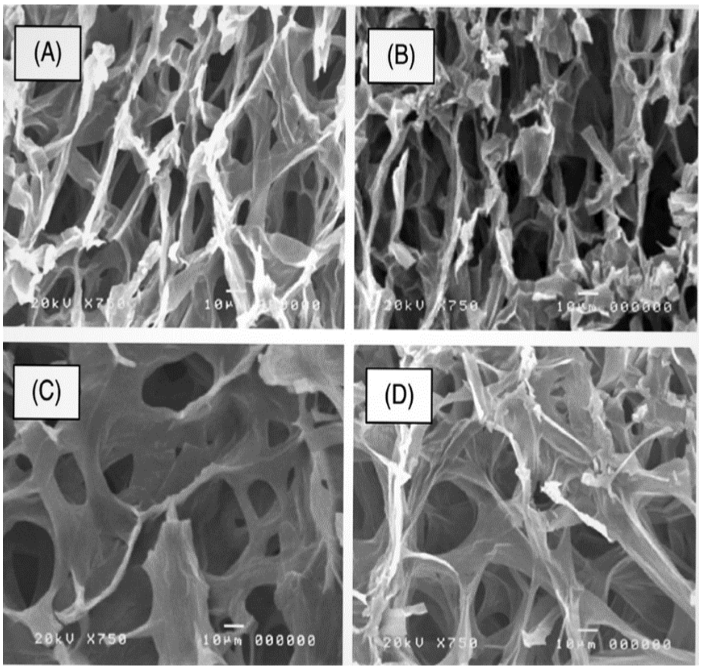

Figure 2. Scanning electron micrographs of shiitake mushrooms dried with different methods (Tian *et al*., 2016).

The magnification was set as ×750: (A) hot air dying (HAD), (B) microwave drying (MD), (C) vacuum drying (VD), and (D) microwave vacuum drying (MVD).

3.1.1 Solar drying

Laying the mushrooms thinly on a tray and exposing them to sunlight and wind is the most common process. However, the open sun drying process can cause considerable loss and quality degradation because of susceptibility to contamination, incomplete drying, microbial growth, and other reasons. This open surrounding drying is called sun drying. In addition, natural sun drying is highly dependent, and therefore limited, on weather conditions. Solar energy is a clean, free, and available source of energy which is regarded in various contexts as an important source of energy for the drying treatment (Ghasemi *et al.*, 2021). Some solar dryers have progressed to increase the efficiency of drying, in which the mushrooms are held within a chamber, to address these disadvantages (Nölle *et al.*, 2017). As drying itself is an energy-intensive processing technology, solar drying is a good way to deal with the energy crisis and the global greenhouse effect. Reyes *et al*. (2013) used a hybrid solar dryer to dehydrate mushrooms which included a 3 square metre solar panel and electrical resistances. About 3.5% to 12.5% of the overall power was saved by solar power. There are many benefits to solar drying, including energy saving, low investment, and easy operation.

3.1.2 Hot air drying

The easiest dryer commonly used worldwide is hot air drying. Placing mushrooms on a tray and moving them into a cabinet or tunnel dryer is a popular hot air-drying process. Heating to a temperature of 50-70°C, the hot wind removes the moisture within the mushroom along with air convection, thus achieving the drying function (Argyropoulos *et al*., 2011). Elevated temperature and air convection speed are conducive to the drying of mushrooms from the perspective of drying speed alone. If the water moves very rapidly on the surface of the mushroom, however, the inner water could not move to the surface, and the surface may become overheated. As this system happens, the mushroom's moisture content will decrease, and the drying rate requires more energy. Improper use of hot air drying on mushrooms can cause distinctive changes in colour, structural deformations (Kotwaliwale *et al*., 2007) and heat-labile nutrients like vitamin C (Bashir *et al*., 2020).. To overcome these problems, modern alternative methods such as freeze drying, microwave drying, and infrared drying have emerged one after another. These drying techniques have been implemented separately or combined with hot air drying. Furthermore, the application these innovative techniques have potential in reducing the environmental effect of food production

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with an increase of safety (Gharibzadeh *et al*., 2023).

3.1.3 Freeze drying

Freeze drying is a very successful method of drying that has been used to dehydrate heat-sensitive foods of high value. The phase change of moisture in freeze-drying is unique compared with other drying methods. Frozen water is sublimated directly from solid ice to water vapour in the freeze-drying process (Bashir *et al*., 2020; Jiang *et al*., 2020). However, in other types of dryers such as hot air drying, and vacuum drying, the water in the product is converted to liquid-state vapour. Most microbial activity and enzyme reactions are stopped because of the low temperature and lack of liquid water, resulting in high-quality products. Low-temperature conditions, especially the heat-sensitive components, can better protect the nutrients in mushrooms. Water molecules vaporise directly from the solid form during freeze drying, which preserves the main structure and shape of the mushroom with a minimum reduction in volume. Freeze drying is considered one of the best methods of drying because of its outstanding success in preserving the consistency of dried products (Duan *et al*., 2008).

3.1.4 Microwave-related drying mushrooms

Microwave drying has the benefits of faster drying due to volumetric heating, less heat loss, smaller equipment footprint and simple automatic control compared to traditional drying methods. The correct microwave drying technology will dramatically reduce drying time and increase the quality of the product (Jiang *et al*., 2020; Sun *et al.*, 2023). Instead of conventional thermal drying, mushrooms can be dried by microwave or microwave-assisted drying as a kind of heat-sensitive product. Despite this, Continuous microwave exposure can cause local overheating, especially if the geometry of the product is undefined (Arora *et al*., 2018). Walde *et al*. (2006) stated that prolonged exposure can cause the mushrooms to scorch, especially around the edges, and cause hardening of the surfaces.

3.1.5 Far-infrared drying

The advantages of rapid drying rate, consumption of energy, standardized heating and high product quality are infrared drying (Jiang *et al*., 2020). Far infrared is more appropriate for product drying among various infrared technologies, as most food items can absorb far-infrared radiation energy (Krishnamurthy *et al*., 2008). There are also several types of research based on the use of infrared or infrared-assisted mushroom drying technology. Zhao *et al*. (2019) assessed the nutritional, structural, and sensory properties of *L. edodes* prepared by five drying methods, including hot air drying, hot air combination drying of instant regulated pressure drops, freeze drying, drying of heat pumps and drying of far-infrared radiation. The findings showed that far infrared drying speed is high, which can save up to 66.25% time compared to freeze drying.

Greater appearance quality and more flavour compositions, particularly the content of certain sulphur compounds up to 24.59% were shown by the far infrared dried *L. edodes*. Far infrared dried *L. edodes* had better overall quality among the five drying methods (Zhao *et al*., 2019).

3.1.6 Osmotic drying

One of the energy-efficient means of dewatering processes requiring the partial elimination or dilution of water from food products is osmotic dehydration. This works by soaking food in a solution of higher osmotic pressure or hypertonic or concentrated solution, such as salts, alcohols, starch, and concentrated sugar solutions (Ramya *et al*., 2014). As an efficient process, osmotic dehydration can be used to extract water from vegetable tissues while adding solutes to the product simultaneously. The solute residues inside the product not only affect the taste and flavour of the product, but also the dielectric properties of the product. Mushrooms are osmotically pre-treated with a sodium chloride solution according to Torringa *et al*. (2001) and subsequently dried by combined microwave or hot air heating application. A strong influence on the loss factor is the increased concentration of salt. The results show that because of the reduced centre heating, the mushrooms are more homogeneously heated have a slightly shorter drying time, show better rehydration properties, decreased shrinkage, and greater open pore porosity (Torringa *et al*., 2001).

4. Application of the drying method

Dehydration is a conventional food preservation strategy focused on the theory that reducing the operation of water during drying can prevent microbiological and physicochemical changes responsible for spoilage. Table 1 represents the chemical properties of mushrooms for different drying methods. All the drying techniques have resulted in a decreasing trend in the moisture content of many mushroom varieties. Sun-dried samples had the highest moisture content (8.84%) followed by solar-dried samples with a moisture content of 8.08% (Bashir *et al*., 2020). In oven-dried oyster mushrooms, the moisture content of 7.32% was found to be lower sun-dried and solar-dried, which agrees with previous findings (Maray *et al*., 2018). This trend shows the same for *L. edodes* which is the highest moisture content recorded by sun-dried (8.45%), followed by solar-dried (7.4%) and oven dried (3.74%). This may be due to fluctuating temperature and relative

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Table 1. Chemical properties of different drying methods on *Pleurotus* spp. and *L. edodes*.

Mushroom species	Drying method	Moisture (%)	Crude protein (%)	Carbohydrate (%)	Crude fat (%)	Crude fibre (%)	Total ash (%)	References
P. florida	Sun drying	8.84	20.36	48.16	3.46	24.09	8.12	Tolera and Abera (2017); Bashir *et al*. (2020)
	Solar drying	8.08	21.05	-	3.54	24.15	8.27	Bashir *et al*. (2020)
	Oven drying	7.32	22.86	-	3.86	25.26	8.48	Bashir *et al*. (2020)
	Microwave drying	6.97	22.56	-	3.68	25.38	8.36	Bashir *et al*. (2020)
	Freeze drying	5.16	23.74	-	4.06	25.01	8.82	Bashir *et al*. (2020)
	Osmotic drying	6.23	21.79	-	3.72	22.83	9.37	Bashir *et al*. (2020)
L. edodes	Sun drying	8.45	25.91	42.14	2.18	10.41	10.91	Tolera and Abera (2017)
	Solar drying	7.14	22.69	-	-	-	-	Tian *et al*. (2016)
	Oven drying	3.74	22.19	-	3.88	-	11.12	Yang *et al*. (2019); Liu *et al*. (2020)
	Microwave drying		22.57	-	3.65	-	11.01	Tian *et al*. (2016)
	Freeze drying	3.57	22.09	-	4.00	23.56	11.44	Krittalak *et al*. (2018); Yang *et al*. (2019)

humidity during sun drying than oven drying that uses uniform temperature for efficient removal of moisture (Muyanja *et al*., 2014). Osmotic dried mushrooms showed a lower moisture content of 6.23% relative to oven-dried oyster mushrooms, which may be due to greater water loss during osmosis (Tolera and Abera, 2017). Unlike other drying techniques, freeze-drying requires the sublimation of frozen moisture to direct vapours, resulting in greater water loss. The higher the moisture content remains means the lowest the moisture loss during the drying process.

The various drying methods had a major effect on the crude protein proportion of oyster mushrooms. The freeze-dried oyster mushrooms had the most amount of crude protein followed by oven-dried oyster mushrooms with a crude protein percentage of 22.86%, while the sun -dried (20.36%) and osmotic dried (21.79%) oyster mushrooms had the least crude protein content consistent with the results of Oni *et al*. (2015) and Munaza (2018), while investigating the effect of various drying methods on different botanicals and quince, respectively. Concerning freeze drying which resulted from better crude protein retention, the higher temperature used during oven drying could be responsible for protein denaturation and consequential protein loss (Tolera and Abera, 2017). In comparison to sun and solar drying, uniform exposure and short drying times associated with oven drying may be responsible for less protein degradation (Ngabo *et al*., 2016). Higher protein content was recorded in mushrooms subject to freeze drying while investigating the effect of drying methods on the protein content of mushrooms than in mushrooms subject to osmotic treatment and oven drying during the investigation. This can be seen in the protein content of drying *L. edodes* as freeze-dried (22.09%) was lower than oven dried (22.19%). The microwave-dried mushroom's crude protein content was found to be lower than oven-dried samples, which may be attributed to rapid browning reactions involving proteins that account for protein loss. The crude protein content of the osmotic dried mushroom was found to be lower than that of the mushroom subjected to oven drying. Tolera and Abera (2017) reported low protein content relative to the oven dried mushroom compared to osmotic treated oyster mushroom. During the steeping phase of osmotic therapy, leaching of low molecular weight soluble protein fragments may be responsible for a considerable reduction in crude protein.

In terms of fat content, oyster mushrooms and shiitake mushroom are very low. The drying methods resulted in a decrease in the crude fat content of oyster mushrooms that could be attributed to oxidative losses, as mushroom fat consists mainly of polyunsaturated fatty acids that are susceptible to oxidation when mushroom slices are exposed to the drying medium. In contrast to other drying methods similar to Oni *et al*. (2015), the freeze-drying method retained a higher amount of crude fat content (4.06%) and reported better crude fat retention in freeze-dried edible botanicals compared to sun and oven drying. According to Table 1, the crude fat in *L. edodes* shows the freeze-dried as the highest (4.00%), followed by oven dried (3.88%), microwave dried (3.65%) and sun dried (2.18%). In contrast to oven-dried samples, the osmotic dried oyster mushroom showed lower crude fat content, coinciding with the results reported by Tolera and Abera (2017), while

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studying the impact on the quality of oyster mushrooms of various drying methods. During osmotic drying, the greater decrease in crude fat content could be attributed to leaching losses that take place during steeping. In contrast to the oven-dried mushroom, the microwave-dried oyster mushroom reflected a low 3.68% crude fat content. In the range of 22.83% to 25.38%, the dried oyster mushrooms exhibited crude fibre content. These values are in accordance with the dried *P. florida* mushroom values recorded by Alam *et al*. (2008). The quality of crude fibre followed the dried microwave order, followed by oven-dried, freeze-dried, solar-dried, sun-dried, and osmotic dried. This may be due to the increased sensitivity of lignocellulosic substances to microwave response enzymatic activity (Sengupta *et al*., 2012). Sun and solar-dried samples' crude fibre content was found to be 24.09% and 24.15%, which is lower than the oven-dried mushroom, respectively. Tolera and Abera (2017) recorded similar findings while researching the effects of sun and solar drying on oyster mushrooms. Compared to the sun and solar drying methods, the oven drying method may be responsible for higher cell disruption, leading to greater susceptibility to enzymatic operation, thereby increasing the content of crude fibre. The crude fibre of *L. edodes* with freeze-dried was 23.56% which is higher than sun drying which is 10.41%. In comparison to the oven-dried study, the osmotic dried oyster mushroom showed lower crude fibre content compared to the results of Tolera and Abera (2017), which recorded a decrease in crude fibre content with osmotic treatment in bitter leaf (*Vernonia amygdalina*) and oyster mushroom, respectively. This may be due to cell structure changes such as pectin degradation and solute diffusion during osmotic treatment (Tadesse *et al*., 2015).

The highest total ash content was recorded in osmotic dried mushrooms, corresponding to a value of 9.37%, when evaluating the effect of drying methods on the ash content (Bashir *et al*., 2020). This may be due to the diffusion during the steeping process of sodium ions from bringing or steeping solution into mushroom slices as water migrates from mushroom slices (Maray *et al*., 2018). The total ash content of the freeze-dried sample (8.82%) was found to be higher than the total ash values of 8.48% and 8.36%, respectively of the oven and microwave-dried samples (Bashir *et al*., 2020). This may be because of the low temperatures and vacuum used during freeze drying, resulting in better mineral preservation and higher total ash values (Gunya *et al*., 2016). The *L. edodes* also show a similar trend as the total value for freeze-dried is the highest (11.44%) followed by oven dried (11.12%), microwave dried (11.01%) and sun-dried (10.91%). In response to microwaves, the formation of stable compounds such as aluminium or ferric oxides may be responsible for greater mineral loss and subsequent low ash content of microwave-dried oyster mushrooms than oven-dried (Arslan *et al*., 2010). The minimum value of total ash corresponding to 8.12% was expressed in the sun-dried oyster mushrooms. In comparison to other drying methods, the comparatively lower ash content of sun and solar-dried oyster mushroom may be due to prolonged air exposure and the fluctuating temperature and humidity contributing to greater mineral loss (Chan *et al*., 1997). It is also the same for *L. edodes* which recorded sun-dried as the lowest ash value (10.91%) among another drying method (Tolera and Abera, 2017).

The absence of lipid water and the low temperature required for the freeze-dried process could mitigate deterioration and microbiological reactions, according to Yang *et al*. (2019) thus ensuring excellent dried food quality. After drying for 48 hours, the moisture content of the freeze-dried mushroom decreased from 89.61% to 3.57%, which is suitable for long-term storage. To give a moisture content of about 13% and lower, the fresh mushrooms should generally be dried (Yang *et al*., 2019). On the other hand, the remaining moisture content decreased correspondingly with the increase in drying temperature. Most of the research on shiitake mushroom mention the 'dried' mushroom without stating the specific drying treatment. It is still a low number of research that investigate the physicochemical properties of shiitake mushrooms especially for osmotic drying, microwave drying and oven drying as for the traditional drying method.

4.1 Substituted mushroom powder products

The global incidence of diabetes is expected to rise from the existing 382 million people to 592 million by 2035, meaning that diabetes will affect approximately 10% of the population. Through diet control, this crippling chronic metabolic condition may be reversed. To promote blood glucose monitoring, market demand for diabetes-related functional foods has increased tremendously (Ng *et al*., 2017). The idea of a glycaemic index (GI) is a promising approach to investigating the physiological effects of food which is an importance that is given to foods in terms of their impact on post-meal glycaemia (Jenkins *et al*., 2008). Because of the slow digestion and absorption rate of carbohydrates, low-GI food causes a steady increase in the amount of blood glucose and is thus considered a significant dietary approach to diabetes management. Recently, due to their better nutritional characteristics, edible fungi have been increasingly used as good dietary fibre (DF) sources in world markets (Cheung, 2013). Mushrooms are also being used in supplemental foods, another miraculous product. Due to their high and good quality protein,

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Table 2. Chemical properties of *Pleurotus* spp. and *L. edodes* substituted products.

Products	Inocula-tion (%)	Carbohydrate (gm)	Protein (gm)	Fat (gm)	Dietary fibre (gm)	Moisture (gm)	Ash (gm)	Energy (kcal)	Calcium (mg)	Iron (mg)	Potassium (mg)	Sodium (mg)	Niacin (mg)	Beta-glucan	Sucrose	References
Noodles fortified with *P. ostreatus*	0%	76.5±0.2	12.7±0.06	0.12±0.05	0.1±0.05	7.9±0.08	1.7±0.05	366±0.25	20.0±0.18	2.1±0.02	64±0.13	416.6± 0.08	-	-	-	Parvin *et al.* (2020)
	5%	74.7±0.29	14.4±0.08	1±0.06	0.6±0.07	7.4±0.05	1.7±0.04	366.2±0.2	27.58±0.16	5.2±0.03	270.5±0.04	753.4±0.05	-	-	-	Parvin *et al.* (2020)
	8%	73.3±0.2	14.7±0.07	1.7±0.05	1±0.03	7.3±0.07	1.8±0.06	367.5±0.4	30.6±0.21	6.1±0.03	414.1±0.07	910.2±0.04	-	-	-	Parvin *et al.* (2020)
	10%	70.5±0.2	16.5±0.08	2.1±0.08	1.4±0.04	6.9±0.04	2.4±0.09	357.4±0.1	38.62±0.21	6.5±0.05	910.2±0.04	987.2±0.05	-	-	-	Parvin *et al.* (2020)
Sponge cake fortified with *P. sajor-caju*	0%	36.4±0.1	10.2±0.02	19±0.01	0.4±0.00	32.3±0.02	1.7±0.02	-	-	-	-	-	-	-	-	Das *et al.* (2020)
	5%	34.2±0.05	11.6±0.01	19.9±0.0	0.5±0.38	31.3±0.07	1.7±0.01	-	-	-	-	-	-	-	-	Das *et al.* (2020)
	7%	33.8±0.08	12.3±0.01	20.3±0.03	0.8±0.20	30.7±0.02	1.8±0.02	-	-	-	-	-	-	-	-	Das *et al.* (2020)
	10%	33±0.07	14.1±0.02	20.8±0.2	0.9±0.01	29.5±0.01	1.8±0.01	-	-	-	-	-	-	-	-	Das *et al.* (2020)
	12%	32.5±0.01	15±0.01	21.5±0.01	0.9±0.001	29±0.01	1.8±0.002	-	-	-	-	-	-	-	-	Das *et al.* (2020)
Pasta fortified with *P. sajor-caju*	0%	80±1.1	9.9±0.4	0.03±0.01	3.7±1.19	9±0.84	0.9±0.0	360±4.7	-	-	-	-	-	0.44±0.03	-	Nordiana *et al.* (2019)
	5%	78.6±0.07	10.8±0.08	0.1±0.03	6.1±0.40	9.1±0.02	1.1±0.02	359.1±0.3	-	-	-	-	-	0.73±0.03		Nordiana *et al.* (2019)
	10%	76.8±0.2	12±0.2	0.2±0.01	7.8±0.17	9.2±0.05	1.5±0.01	358.2±0.3	-	-	-	-	-	0.76±0.11		Nordiana *et al.* (2019)
	15%	76.3±0.09	12.2±0.06	0.4±0.01	0.7±0.11	9.3±0.01	1.7±0.04	357.7±1.9	-	-	-	-	-	1.1±0.13		Nordiana *et al.* (2019)
Biscuit fortified with *P. sajor-caju*	0%	68.5±0.08	6.5±0.06	22.6±0.06	3.3±0.19	1.3±0.05	0.8±0.02	499±1.9	-	-	-	-	-	0.12±0.01	12.8±0.06	Ng *et al.* (2017)
	4%	68.2±0.54	6.9±0.1	22.7±0.3	6.1±0.06	1.3±0.09	0.8±0.04	499.3±2	-	-	-	-	-	1.06±0.03	12.8±0.41	Ng *et al.* (2017)
	8%	67.4±0.2	7.4±0.2	22.9±0.2	8.6±0.14	1.2±0.13	0.9±0.08	499.4±3	-	-	-	-	-	1.2±0.04	12.7±0.26	Ng *et al.* (2017)
	12%	66.9±0.9	7.8±0.1	23±0.46	9.8±0.12	1.1±0.15	1±0.10	499.4±2	-	-	-	-	-	1.7±0.09	12.8±0.19	Ng *et al.* (2017)
Cookies fortified with *P.tuber-regium*	0%	62.4±0.5	9.4±0.06	10.4±0.06	1 ±0.03	15.3±0.30	1.2±0.04	-	227.15±0.20	24.9±0.04	47.5±0.03	66.3±0.04	2.8±0.1	-	-	Kolawole *et al.* (2020)
	10%	64.6±0.6	7.9±0.08	9.8±0.08	2.3±0.03	12.6±0.32	2.5±0.07	-	321.15±0.04	29.1±0.10	61.4±0.04	72.8±0.04	2.9±0.06	-	-	Kolawole *et al.* (2020)
	20%	62.3±1.4	9.5±0.03	9.7±0.06	2.9±0.07	12.2±0.23	3±0.04	-	311.22±0.98	29.8±0.27	63.6±0.04	74.5±0.06	2.8±0.10	-	-	Kolawole *et al.* (2020)
	30%	59.8±0.6	11 ±0.07	9.7±0.04	3.6±0.07	12±0.07	3.7±0.04	-	281.67±0.07	30.5±0.07	65.2±0.48	76.9±0.04	2.9±0.06	-	-	Kolawole *et al.* (2020)
Biscuit fortified with *L. edodes*	0%	66.6±0.5	6.3±0.17	23.8±0.4	-	2.5±0.13	0.8±0.19	504.8±5								Van and Thu (2018)
	5%	70.4± 0.8	6.6±0.1	17.8±0.3	0.4 ±0.14	4.1±0.20	1±0.52	465.9±2.4								Van and Thu (2018)
	10%	70.9±0.06	6.8±0.15	17.6±0.2	0.6 ±0.21	3.4±0.38	1.3±0.04	469.8±0.9								Van and Thu (2018)
	15%	66.6±0.06	7.2±0.22	18.5±0.09	0.9 ±0.14	4.7±0.45	1.6±0.03	465.5±1.5								Van and Thu (2018)
Bread fortified with *P. ostreatus*	0%	52.7	9.1	6.1	1.2	31.1	1.8	-	12.00±0.05	2.4±0.02	66.5±0.04	33.5±0.08	-	-	-	Oyetayo and Oyedeji (2017)
	5%	37.4	18.5	8.6	1.9	29.6	3.8	-	16.00±0.09	2 ±0.02	61.5±0.01	48±0.08	-	-	-	Oyetayo and Oyedeji (2017)
	10%	36.9	19.6	8.1	2.3	29.0	3.9	-	18.07±0.04	2±0.03	68.4±0.09	50.1±0.05	-	-	-	Oyetayo and Oyedeji (2017)
	15%	33.5	22.3	8.5	3.1	28.1	4.2	-	20.00±0.02	1.3±0.05	70.1±0.01	51.3±0.01	-	-	-	Oyetayo and Oyedeji (2017).
	20%	27.9	25.6	8.9	4.2	28.1	4.5	-	24.05±0.06	3±0.03	70.3±0.09	60.8±0.03	-	-	-	Oyetayo and Oyedeji (2017)
Bread fortified with *L. edodes*	0%		9±0.09	4.8±0.17		28.2± 0.1	1.4±0.04									Kim (2017)
	10%		0.8±0.30	8.6±0.18		25.7±0.6	1.8±0.04									Kim (2017)
	20%		9.8±0.06	7.6±0.06		29.7±0.3	1.6±0.02									Kim (2017)
	30%		7.6±0.36	7.6±0.36		32.4±0.2	1.4±0.02									Kim (2017)

mushrooms have a wide potential of about 20% to 40% on a dry weight basis, vitamins especially vitamin B-complex, and minerals (Farzana and Mohajan, 2015). Mushrooms can then be dried and processed into powdered forms, which can be used in baked goods products (Oyetayo and Oyedeji, 2017) such as noodles, cake, pasta, biscuit, and bread for fortification. Several food products that have been added to mushroom powder and its chemical properties have been presented in Table 2. According to Nordiana *et al*. (2019) oyster mushrooms (*Pleurotus* spp.) have been notably marketed and eaten by several varieties of edible mushrooms. They provide better taste and higher levels of nutritious components, including proteins, carbohydrates, vitamins, and minerals. Among many others, shiitake mushroom is one of the most popular foods promoting health mushrooms and shiitake products are ideal for the balanced food industry (Jong and Birmingham, 1993).

4.1.1 Noodles

Noodles are more popular as snacks among children and adults, but noodles made from wheat flour alone are a poor source of dietary fibre (DF), proteins, and minerals. Therefore, fortifying the noodles with mushrooms will solve it. Parvin *et al*. (2020) proposed that in contrast with other marketed noodles, mushroom-fortified noodles (MFN) had higher amounts of protein, fibre, iron, calcium, and potassium. In the experimentally prepared noodles, this finding also demonstrated a lower proportion of starch, fat, and sodium. It may therefore be good for human health. By obtaining healthy noodles with high nutritional values, health benefits, attractive eating qualities, and the cost-effectiveness of noodle products, several researchers have now focused on the quality enhancement of noodles by fortification. The proximate value of *P. ostreatus* mushroom-fortified noodles showed that the carbohydrate content was coincidentally decreased with the increase in wheat flour mushroom content. It is due to low and non-digestible carbohydrates such as resistant starch, oligosaccharides, chitin, and β-glucans (Manzi *et al*., 2001) may be present and develop laxation, stimulate the production of short-chain fatty acids (SCFA) and influence gut microbial

Figure 3. Dried and cooked noodles fortified with different percentages of mushroom powder (Parvin *et al*., 2020).

species (Hess *et al*., 2018). The biochemical, physical, and sensory features of fortified noodles were significantly ($P<0.05$) affected by 5% mushroom powder. Figure 3 shows cooked and dried noodles fortified with various proportions of mushroom powder. This produced noodle was appropriate based on the organoleptic assessment, and it was found to be superior compared to locally available branded noodles in Bangladesh (Parvin *et al*., 2020). Next, the oyster mushroom (*P. sajor-caju*) is very common among the different varieties for its saccharidic complex. The saccharidic complex of oyster mushrooms is distinguished by a low digestible carbohydrate content and a relatively high polysaccharide content, which is involved in the processing of edible fibre (Strmiskova *et al*., 1992). The main ingredient of baked goods such as wheat flour is found lacks many nutrients, including vitamins, minerals, and dietary fibre (Ayo and Nkama, 2003). In this respect, to substitute wheat flour along with other ingredients, the mushroom powder can be added as a source of protein, ash, and fibre to make functional food high in demand.

4.1.2 Cake

Das *et al.* (2020) found the protein, fat, ash, and fibre content in the cake was increased by enhancing the amount of fortification from 0% to 12% mushroom powder. Das *et al.* (2020) stated the relative compositions of sponge cakes with mushrooms at five different fortification percentages (0%, 5%, 7%, 10%, and 12%) indicate that the rise in fortification level from 0% to 12% results in protein content ranging from 10.20% to 15.08%. The addition of mushroom powder increased the sponge cake's protein, fat, ash, and fibre content. Increasing the amount of mushroom powder from 5% to 12% substantially increased the protein, fat, ash, and fibre content of the cake, while the sugar content showed a reverse trend. However, except for carbohydrates, freeze-dried mushrooms added higher nutritional parameters at each stage of fortification compared to hot air-dried mushrooms. The controls produced the highest content of carbohydrates and moisture. The weight of the cake was raised, and with the rise in the amount of mushroom powder, the volume was decreased, and the cake prepared with freeze-dried mushroom powder exhibited greater weight and lower volume than with hot air-dried mushrooms. This is due to increased water holding capacity. The sensory attribute test showed that the colour, taste, texture, and overall acceptability of cakes varied significantly ($p \leq 0.05$) at different levels of mushroom powder, but it is more satisfying to partly replace wheat flour with 10% freeze-dried mushroom. The present study concluded that 10% of freeze-dried mushroom powder can be

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due to the initial high protein and ash concentrations in MP. Nutritional analysis of the biscuits made using 5% to 15% of *L. edodes* powder replacement showed the most slightly increased fibre and protein content compared to the wheat flour biscuit produced (Van and Thu, 2018). In the biscuit formulations, however, there was an opposite relationship between moisture content and the degree of incorporation of MP. As compared with the control biscuit, the moisture content of the biscuits was shown to decrease considerably ($P<0.05$) at 8% and 12% MP incorporation. The same result also represents by Van and Thu (2018) for *L. edodes*. This is because a significant amount of water can be absorbed by the DF content in MP, steadily leading to a decrease in the moisture content.

Enriching DF in bakery products can lead to noticeable losses in odour, texture, appearance, taste, and mouthfeel. Since functional food with acceptable sensory characteristics is of major concern for fulfilling consumers' expectations, the addition of 8% PSC powder is the most effective way to produce palatable and low-GI biscuits without negatively changing its desirable sensory characteristics. According to Van and Thu (2018), the addition of 5% *L. edodes* powder is much more attractive than others. Consumers may accept the addition of 5%, 10% and 15% of *L. edodes* powder. By incorporating wheat flour with *L. edodes* powder in the production of biscuits, the improved nutritional values, and the development of new recipes for making high-quality biscuits from *L. edodes* were successfully obtained.

4.1.5 Bread

The mineral premix and proximate fortified bread with *P. ostreatus* mushrooms was determined by Oyetayo and Oyedeji (2017). The mushrooms were dried and milled into powder. The mushroom powder was used in bread formulation to replace wheat flour at 0%, 5%, 10%, 15% and 20%. The bread's proximate and mineral properties were calculated using standard methods before and after storage. The study showed that with the addition of mushroom powder, the content of ash, fibre and protein increased significantly while carbohydrate content reduced. Kim (2017) recorded the same trend for *L. edodes*. Besides, as the mushroom powder increased, the potassium, sodium, calcium, magnesium, manganese, copper, zinc, and iron content of the bread increased significantly ($P\leq0.05$). Calcium, manganese, copper, iron, magnesium, potassium, Sodium and zinc content increased considerably in bread ($P\leq0.05$). After processing, the mineral composition of the fortified bread indicates a rise in the sodium content with an increase in mushroom concentration and a similar increase in the potassium content has been observed. This can be attributed to the initial content of the mushrooms. As the mushroom content rose, the calcium and magnesium content of the bread was observed to increase, these findings were confirmed by the study by Bano *et al*. (1988). Similar increases in the magnesium, potassium, calcium and sodium content of mushroom-enriched bread have been documented. However, it can be concluded that bread fortification with 20% mushroom powder was most successful in raising the bread's nutrient content.

5. Mushroom bioavailability in human gut system

According to Jayachandran *et al*. (2017), mushrooms act as a prebiotic to promote gut microbiota rise, deliberating health insurance to the host. Prebiotics depress endogenous pathogens present in the gastrointestinal tract, helping the immune system combat exogenous pathogens with enhanced competence (Valdemiro, 2011). Mushrooms are rich in polysaccharides, particularly β-glucans, which can stimulate the immune system and give medicinal mushrooms beneficial properties. Non-digestible mushroom polysaccharides are the significant sources of prebiotics in mushrooms that can prevent pathogen proliferation by promoting the growth of probiotic bacteria in the gut (Bhakta and Kumar, 2013). Yin *et al*. (2020) reported many experimental studies *in vitro* and *in vivo* have shown that mushroom polysaccharides can control microbiota in the gut. According to Su *et al*. (2019), *Flammulina. velutipes* polysaccharides modulated the composition of gut microbiota by increasing the amounts of *Bifidobacteriaceae* and *Bacteroidaceae and* lowering the numbers of genera *Lachnospiraceae* and *Enterococcaceae* in an *in vitro* fermentation test. Zhao *et al*. (2019) showed consumption of *Auricularia auricular* polysaccharides significantly decreased the *Firmicutes* to *Bacteroidetes* ratio and enriched the diversity of faecal microbiota in mice.

6. Conclusion

In conclusion, oyster mushroom and shiitake mushroom has provided many advantages for human life as the mushroom is a source of food and Malaysia is a mushroom producer for the local and export markets. Mushrooms are highly perishable. Drying is a common method used after harvest in the processing of fresh food. Among these different drying methods, freeze drying is the best technique to use in many types of research as it can maintain most of the nutrition in the mushroom. However, the combination of two or more drying methods will produce better results. The production of new products substituted with oyster mushrooms and shiitake mushrooms may be more nutritious and can provide many benefits to human health. Food products successfully incorporated into sponge cake with appropriate sensory attributes.

4.1.3 Pasta

Pasta is used mainly as an energy source because of its high carbohydrate content. Pasta holds considerable potential for enhancing the nutritional status of the population (Sharma *et al.*, 2020). It has been fortified with various kinds from different sources (Filip and Vidrih, 2015). As oyster mushroom powder contains a large amount of protein (22.4%) and dietary fibres (57.0%), supplementation with oyster mushroom powder to partially substitute wheat flour in pasta is intended to enhance this nutritional composition, as reported by Han *et al*. (2016). Nordiana *et al*. (2019) proposed that due to its capacity to boost the nutritional consistency of the original food product without ignoring the palatability aspects, oyster mushroom fortification (OMF) could potentially be used for the partial replacement of wheat flour in pasta processing. In the pasta formulation, an addition of 10% OMF was found to increase nutritional values, affecting some physicochemical properties while enhancing the sensory qualities of flavour and texture.

Relative to control, all pastas containing 10% and 15% OMF had slightly higher protein content. The 5% to 10% OMF pastas did not vary significantly. The 5% OMF pasta, however had a considerably lower protein content than the 15% OMF pasta. Furthermore, 15% of OMF pasta also showed no noticeable difference from 10% of OMF pasta. Essentially, as the OMF levels rose, the protein content increased. This showed that the nutrient content of OMF substituted pasta was better than OMF free pasta. This may be attributed to the fact that there was a high amount of protein in the OMF used in the current work, varying from 21.01% to 22.41%. Earlier studies performed by Ng *et al*. (2017) also observed that the addition of OMF increased the content of total DF. The addition of OMF raised the humidity significantly, but no statistical difference was observed in the pasta with different amounts of added OMF. Naturally, the oyster mushrooms have high water content and water holding capacity. This may have caused the higher amount of moisture found with added OMF in the pasta. The experiment conducted by Nordiana *et al*. (2019) represented pasta incorporated with *P. sajor-caju* mushroom resulted in a substantial increase in mean values of total ash with rising levels of OMF in the pasta formulation. The findings showed that β-glucan was substantially higher for the 15% OMF pasta than both the control and the 5% OMF pasta. Because of their medicinal properties that are attributable to the existence of β-glucan, mushrooms have been considered as a functional food. Important beneficial health effects such as hypocholesterolaemia, and immunomodulatory behaviours have been shown (Samsudin and Abdullah, 2019). Even though these were not significant, the calorific values of pastas were found to decrease with growing levels of OMF. Increasing the rate of OMF in pasta formulations resulted in a 0.3% to 0.7% reduction in the calorific value. The results showed that the addition of mushroom powder causes the loss of cooking, as well as the quality and strength of the pasta's uniaxial stress (Lu *et al*., 2016). In comparison with the control sample containing exclusively durum wheat semolina, *L. edodes* have no significant effect on either index. The shiitake mushroom powder addition resulted in the tensile strength and the high level of firmness in pasta. It was redder, darker, and less yellow with a rise in mushroom powder (MP). According to Correia *et al*. (2017) sensory analysis showed that for all the parameters evaluated, consumers favoured pasta produced with high mushroom flour content with similar profiles, and the effect of the form of wheat flour was not significant. It can be inferred that it is possible to use mushroom powder to manufacture pasta with better consistency and similar properties to standard pasta.

4.1.4 Biscuits

Next, the study demonstrated by Ng *et al*. (2017) reported the use of a novel solution to produce a palatable high-DF and low-GI biscuit is 8% *P. sajor-caju* (PSC) powder. The low GI of this biscuit could be due to the high DF amount, which, in turn, reduced the viscosity of starch pasting, decreased enthalpy value of starch gelatinisation, disturbed morphology of starch granules and decreased digestibility of starch after incorporation of PSC powder into biscuits. An improvement in the amount of mushroom powder (MP) from 0% to 12% resulted in a substantial increase ($P<0.05$) in the level of protein, ash, total DF, including soluble DF and insoluble DF, and β-glucan, with the highest nutritional values reported by the 12% PSC biscuit (Ng *et al*., 2017). Collectively, the DF content of biscuits could be enriched with MP. This is because PSC powder originally contains a high amount of total DF, including the soluble and insoluble forms of the powder. Food should contain at least 3 g of DF per 100 g of serving to claim that a food is a 'source of dietary fibre'. Meanwhile, the product must contain at least 6 g of DF per 100 g of serving to state that a food is 'high in dietary fibre' (Foschia *et al*., 2013). Therefore, high DF products are known to be mushroom powder-enriched biscuits containing a total DF of 6.19% to 9.84%. Because of the universal consumption of bakery items such as biscuits, DF enrichment provides promising prospects for growing the regular intake of DF by populations.

Besides, the addition of mushroom powder also increased the protein and ash content of biscuits, mostly

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substituted with mushroom powder result in a decrease in carbohydrate and moisture content; and an increase in protein, fibre, ash, and other micronutrients. Thus, the best choice of substrate for cultivation, irradiation treatment and drying method can retain the nutrients of the mushroom-based products.

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