Cultivation and Nutritional Value of Prominent *Pleurotus* spp.: An Overview

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**ABSTRACT**

*Pleurotus* species are commercially essential mushrooms and widely cultivated throughout the world. The production of *Pleurotus* mushrooms alone accounts for around 25% of that total cultivated mushrooms globally. In America and Europe, *Pleurotus* species are considered specialty mushrooms, whereas, in Korea, their cultivation is economically profitable, and it is one of the highly consumed species. *Pleurotus* species are predominantly found in tropical forests and often grow on fallen branches, dead and decaying tree stumps, and wet logs. Biographical studies have shown that the *Pleurotus* genus is among the more conspicuous fungi that induce wood decay in terrestrial ecosystems worldwide due to its formidable lignin-modifying enzymes, including laccase and versatile peroxidases. *Pleurotus* species can be grown easily due to their fast colonization nature on diversified agro-waste and their biological efficiency 100%. *Pleurotus* mushrooms are rich in proteins, dietary fiber, essential amino acids, carbohydrates, water-soluble vitamins, and minerals. These mushrooms are abundant in functional bioactive molecules, though to influence health. *Pleurotus* mushrooms are finding unique applications as flavoring, aroma, and excellent preservation quality. Apart from its unique applications, *Pleurotus* mushrooms have a unique status delicacy with high nutritional and medicinal values. The present review provides an insight into the cultivation of *Pleurotus* spp. using different agro-waste as growth substances paying attention to their effects on the growth and chemical composition.

1. Introduction

*Pleurotus* mushrooms are considered healthy because of richness in proteins, fiber, vitamins, and minerals [1]. *Pleurotus* mushrooms are consumed as a functional food as they attractive taste and aroma, nutritional and medicinal value. *Pleurotus* species (Oyster mushrooms) are commercially important edible mushrooms and cultivated globally [2]. The oyster mushroom basidiocarps are shell or oyster shaped with different colors like white, cream, gray, yellow, pink, or light brown [3]. *Pleurotus* consists of about 40 species distributed in a wide range of tropical and temperate regions [4]. Twenty-six species, including *Pleurotus eryngii* (PE), *Pleurotus citrinopileatus* (PC), *Pleurotus flabellatus* (PFL), *Pleurotus ostreatus* (PO), *Pleurotus djamor* var. roseus (PDR), and *Pleurotus florida* (PF), have been reported to be cultivated using different types of lignocellulosic wastes [3–11]. A large number of *Pleurotus* species were identified and commercialized. However, many of them are yet to be analyzed for their nutraceutical and medicinal potential. They secrete extracellular enzymes to digest the surrounding organic materials to obtain their nourishment. *Pleurotus* species are widely found growing on the damp wood trunk of trees and decomposing organic matters containing rich sources of lignin and phenol degrading enzymes. *Pleurotus* species are cultivated on a large scale using a wide range of agro-substance with simple and low-cost production techniques [12]. Globally, about 998 million tons of agro wastes are produced annually, which include paddy, wheat and cereal straws. *Pleurotus* mushrooms utilize these agro-wastes as substrates for their growth, and thus, the cultivation of them helps in recycling agro-wastes and alleviates the nutritional gap mainly prevalent among the population of China, India and Africa. Additionally, the spent substrates are used as fertilizer, animal feed, and biogas production [13].

Consumption of *Pleurotus* mushroom is increasing due to its high proteins and dietary fiber composition [3,6] as well as essential and non-essential...
amino acids, particularly lysine and leucine. The presence of high mineral content in *Pleurotus* species is considered an important source of meat, fish and vegetables [13,14]. *Pleurotus ostreatus* is cultivated on a large scale, however, their demand in the global market is lower than the button (*Agaricus bisporus*) and shiitake mushrooms (*Lentinula edodes*) [15], due to its shorter shelf-life [16]. They are highly perishable mushrooms with short self-life, drying, and other value-added commodities that may compete in the global market [16]. Extensive research on nutritional and medicinal attributes of *Pleurotus* species has been investigated by many researchers [4,17,18]. The presence of mevinolin, nicotinic acid, and a higher level of β-glucans compounds in *Pleurotus* species has been successfully proved to be a food supplement for cardiac patients to reduce the blood cholesterol level [19]. The current review article discusses ten commercially available *Pleurotus* species, their cultivation methods, and nutritional composition. The presented data will give academics and industrialists an innovative concept from translation *Pleurotus* species from food to medicine.

### 2. Diversity and taxonomy of *Pleurotus*

*Pleurotus* species belong to Agaricales and the family of Pleurotaceae (white spore oyster mushroom) and are distinguished with their color and habitat. Most of them are saprophytic and rarely parasitic. A previous publication by Bao et al. gives us valuable input on the number of *Pleurotus* species distributed in Asia [20]. The morphological characteristics of *Pleurotus* species are unstable due to varying agro-climatic conditions and different substrates used for cultivation [21]. The taxonomical and phylogenetic identification of *Pleurotus* species is quite complex, leading to its misidentification. The genus, species name, and anamorphic states of commercial important *Pleurotus* species were described by Guzman [22] (Table 1). Stajic et al. have reported that the geographical separation causes differences between the isolates genetically [33]. In recent decades, various biochemical and molecular techniques have been employed to investigate the phylogenetic relationships and the taxonomical hierarchy [34].

The DNA based molecular identification techniques such as internal transcribed spacer region identification, random amplified polymorphic DNA (RAPD), amplified fragment length polymorphism (AFLP), and restriction fragment length polymorphism (RFLP) has been widely used to validate *Pleurotus* species [35–38]. Through these genetic diversity studies, the ambiguous taxonomy of *Pleurotus* species may be employed in clarifying the misidentified species and strains in the literature. Also, the molecular identification of the *Pleurotus* species a prerequisite for breeding programs and commercial mushroom production.

### 3. Cultivation of *Pleurotus* species

*Pleurotus* mushroom cultivation is an economically viable and eco-friendly process for converting various agro wastes into human food. *Pleurotus* mushrooms are cultivated on a large scale globally, accounting for 27% of its global production [39]. Africa has successfully developed cultivation methods for sustainable production as a valuable food source to defeat hunger [40]. In Asia, the *Pleurotus* mushroom industry has increased rapidly due to low production cost and high yielding capacity. The cultivation processes include substrates processing, casing, and temperature shocks [41]. Shukla and Biswas have stated that PF cultivation is gaining popularity in India due to low-cost technology and easily available substrates [42]. The mushroom can adopt to grow on a wide range of temperatures, at relatively high humidity and tolerate high CO2.

| Valid taxa | Anamorphic states [22] | Common name | Optimum temperature range (°C) | References |
|------------|-------------------------|-------------|-------------------------------|------------|
| P. ostreatus (PO) | P. Kumm. var. ostreatus | Black Oyster | Spawn running: 21–24 | [23,24] |
| P. floridus (PFL) | P. floridus (Berk et Br) Sacc. | Strawberry Oyster | Basidiocarp production: 25–30 | [8,18] |
| P. rubescens (PR) | P. rubescens var. rubescens | White Oyster | Basidiocarp production: 21–25 | [23,25] |
| P. sajor-caju (PSC) | Lentinus sajor-caju | Gray Oyster | Basidiocarp production: 20–25 | [24,26] |
| P. citrinopileatus (PC) | P. citrinopileatus var. citrinopileatus | Golden Oyster | Basidiocarp production: 18–29 | [3,5] |
| P. eryngii (PE) | P. eryngii | King Oyster | Basidiocarp production: 10–35 | [24,27] |
| P. pulmonarius (PP) | P. pulmonarius | Phoenix Oyster | Basidiocarp production: 20–24 | [28,29] |
| P. djamor | P. eous (PEO) | Pink or red Oyster | Basidiocarp production: 30–35 | [30,31] |
| P. djamor var. roseus (PDR) | P. djamor var. roseus Corner | Roseus mushroom | Basidiocarp production: 20–24 | [10,12] |
| P. tuber-regium (PTR) | Lentinus tuber-regium (Fr) Fr.; Panus tuber-regium (Fr) Corner | King tuber | Basidiocarp production: 30 | [32] |
levels; hence, it does not require sophisticated and specific controlled environmental conditions. The genus *Pleurotus* are ubiquitous, found both in temperate and tropical parts of the world. They are a high delicacy and well-known edible mushrooms in different parts of the world [39]. Cultivation of these mushrooms is a major source of income for farmers and industrialists in South East Asia. Growing this mushroom is becoming more popular globally because of its ability to grow on diversified substrates and temperature tolerance [43]. Mushroom farming has become an essential cottage industrial activity in the integrated rural development program.

The cultivation of *Pleurotus* mushrooms through solid-state fermentation help in the recycling of agro wastes. Various agricultural by-products are used as substrates to cultivate oyster mushroom, for instance, banana leaves, peanut hull, and corn leaves, wheat and rice straw, mango fruits and seeds, sugarcane leaves (Table 2). The widely used substrate for cultivation in Asia is rice straw and cotton wastes [52]. Cotton wastes substrate is the cheapest and suitable substrate for *Pleurotus* mushroom cultivation, mostly generated from the cotton spinning industry. Cotton waste has attracted Korean farmers and has encouraged them in *Pleurotus* cultivation [41]. The biological efficacy among the *Pleurotus* species cultivated on non-compost and compost substrates ranged from 45.33 to 120.07% [12,30].

The most cultivated species of *Pleurotus* are *P. ostreatus* (PO), *P. sajor-caju* (PSC), PF and *P. eous* (PEO), and, particularly, *P. florida* (PF) and *P. sajor-caju* (PSC) are the most popular (Figure 1) [21,53,54]. Going back to history, the *Pleurotus* culture was introduced to China during World war 1 from the West, and the country has achieved approximately 25% of the world’s production in the year 2010 [39,55]. The total production of *Pleurotus* mushroom in Asia was about 825,600 tons in the year 2010 [39]. PO was cultivated in Japan early 1950s, and the bottle cultivation technique of PE (king oyster) was introduced in 1993. They adapted bottle cultivation techniques with either sawdust or corncob as a substrate for large-scale production [56]. The mushroom industry in South Korea is more extensive and diverse, reflecting domestic consumption and traditions. PO, PD, PC, PE, and PSC are cultivated in South Korea, among them, PE is dominating [41,57]. *Pleurotus* mushroom production in South Korea accounted for 52% of the total production [58]. PSC represents a group of strains of *P. pulmonarius* (PP) that are cultivated on a large scale in southern and eastern Asia [20]. *Pleurotus tuber-regium* (PTR) has been widely cultivated and is consumed by the African peoples and also gained popularity in China [59] (Table 3).

3.1. Substrate preparation and spawn run time

The selection of appropriate substrate and spawn run time is a challenge, despite its simplicity in large-scale cultivation. Broadleaf, hardwood, sawdust, and straw-based substrates with added supplements are more often used in commercial production. The artificial substrates must be pretreated in a clean environment, mainly to eliminate contaminants [9]. *Pleurotus* species can colonize and produce mushrooms on pretreated conifer (*Pinus* species) wood chips. However, the non-pretreated conifer wood chips substrate inhibits the mycelial colonization presence of inhibitory components [61]. *Pleurotus* species can also utilize wood waste or unused wood residues to promote economic growth and rescue the forest ecosystem. Spawn is a mushroom seed, used to propagate the mushroom

| Organisms | Different substrate used for cultivation | References |
|-----------|----------------------------------------|------------|
| PO        | Paddy straw, cereals straw, wheat straw, barley straw, maize straw, sugarcane bagasse, maize stem residue, wheat stalk, cotton waste, corn husk, rice husk, banana leaves, elephant grass, bamboo leaves, soybean straw, *Triplochiton scleroxylon* sawdust, beech sawdust, flax shives | [11,21,23,44-46] |
| PFL       | Sawdust of mango (*Mangifera indica*), jackfruit (*Artocarpus heterophyllus*), coconut (*Cocos nucifera*), Kadom (*Anstrocephalus sinensis*), Mahogany (*Swietenia macrophylla*), Shiits (*Albizia spp.*), Jam (*Syzygium spp.*), sisal decortication residue | [8,47] |
| PF        | Paddy straw, wheat straw, barley straw, soybean straw, sorghum straw, maize stem residue, cotton waste, maize stems, maize cob shells, pseudo banana stems, oak sawdust | [23-25,30] |
| PSC       | Paddy straw, wheat straw, wheat stalk, cotton waste, maize stems, maize cob shells, pseudo banana stems | [21,24,30] |
| PC        | Paddy straw, *Brassica* straw, Radish leaves, cauliflower leaves, pea pod shell | [3] |
| PE        | Paddy straw, wheat straw, soybean straw, sorghum straw, wheat stalk, cotton waste, cotton seed hull, cotton stalk, beech sawdust, flax shives, maize stems, maize cob shells, pseudo banana stems, beech sawdust, flax shives | [21,30,46,48,49] |
| PP        | Rice straw, cotton waste, banana leaves, *Chrysoscodius lotuicaps* leaves, wood chippings, | [28,50] |
| PEO       | Paddy straw, wheat straw, soybean straw, sorghum straw | [30] |
| PDR       | Paddy straw, ragi straw, corn straw, coir pith, sugarcane bagasse | [10,12] |
| PTR       | Paddy straw, wheat straw, corn straw, saw dust, oil palm fiber wastes, wild grass straw, poultry dropping, maize cob, cassava peelings, dry water hyacinth, millet stalk, groundnut shell, banana leaves, cocoa leaves, paper wastes | [32,51] |
mycelia in the desired solid substrate during cultivation. The temperature of the spawn room was maintained between 25 and 30 °C. The spawn run period and primordial initiation were generally observed during 24–30 d [62,63]. The spawn running and basidiocarp production temperature also depends on the *Pleurotus* species that is being cultivated (Table 1). Light is not a prerequisite in the spawn running.
room. Spawning is done in the cleaned spawning area in the bulk chamber. The preparation of spawn needs to be standardized for different Pleurotus species.

For instance, one kg of healthy grains was washed thoroughly in tap water and boiled with 1.5 L of water for about 30 min until they become soft and soaked for about 12 h [64]. The grains were spread on a sterile surface to drain out the excess of water. To the drained grains, 15 g of calcium carbonate was mixed to make the grains free from clumps. Two hundred grams of grains were taken in polypropylene bags (18 cm × 12 cm) plugged with cotton and were sterilized at 121 °C for 20 min. After cooling at room temperature, the mycelium from a Pleurotus culture is placed onto sterile grain and incubated for mycelia growth. Sawdust can also be used as an alternative to seed grains, and both the substrates were mixed with rice/wheat bran-based materials. Recent, liquid spawn, stalk, and stick spawn are being used for Pleurotus mushroom cultivation (Figure 2) [65,66]. Spawning is done at a 2% spawn rate (2 g/100 g wet substrate). The seeded substrates, broth, stalk, and stick (mycelia bit/through spawning) are inoculated in the cultivation substrates (perforated polythene bags, polypropylene bottles, and trays). Different types of cultivated methods were employed in Pleurotus production, for instance, wall-frame, shelf, tray, jar, bag, bottle, and grid-frame methods [67]. The most practiced method includes shelf cultivation, a bag, and a bottle. The shelf (row/bed) cultivation method is considered as a low cost and high production technique. In the bag cultivation method, the spawn is tied on the top and is placed horizontally in rows. The advantages of plastic bottle cultivation are high yield and efficiency with limited land space [53]. Cultivation bags and bottles were placed vertically are horizontally for spawn running, and the spawn incubation chamber was maintained at 24–25 °C and 90% RH. The incubation time and temperature for spawn run varied among the species. PEO (30–35 °C) and PE (10–35 °C) are high temperature tolerant [27,31], while the optimum growth

| Species | Korea | India | Japan | America | Europe | Africa | Australasia | China |
|---------|-------|-------|-------|---------|--------|--------|-------------|-------|
| PO      | +     | +     | +     | +       | +      | +      | +           | +     |
| PPF     | –     | +     | –     | –       | –      | +      | –           | –     |
| PF      | +     | –     | +     | –       | +      | +      | –           | –     |
| PSC     | +     | –     | +     | +       | –      | +      | –           | –     |
| PC      | +     | –     | +     | +       | +      | +      | –           | +     |
| PE      | +     | –     | +     | +       | +      | +      | –           | +     |
| PP      | –     | –     | +     | +       | +      | +      | –           | +     |
| PEO     | –     | –     | –     | –       | –      | +      | –           | –     |
| PDR     | +     | +     | +     | +       | –      | +      | –           | –     |
| PTR     | –     | –     | –     | –       | –      | +      | –           | +     |

*+* reported Pleurotus species; “-” species has not yet been reported.

Figure 2. Production of liquid, stalk, and stick spawn of Pleurotus species. (a) pilot scale liquid spawn production; (b) corn stalk chips in Pleurotus liquid broth; (c, d) mycelial growth on stalk chips before and after 3-(4,5-dimethylthiazol-yl) -2,5-diphenyltetratolium bromide (MTT) staining; (e, f) longitudinal sections of logs (stalk, stick) inoculated with different types of spawn [(b–f) adapted from Liu et al. 2018].
temperature for PTR was in a range between 30–35 °C [32], even though the optimum temperatures for oyster mushroom cultivation ranges between 21–25 °C (Table 1).

The Pleurotus species spawn run takes about 12–26 d at 24 ± 1 °C (Table 4). The maximum spawn run period of PP was observed on the 25th day [50]. The spawn inoculated bags/bottles are allowed to colonize (outside becoming white), and they are finally transferred into the cultivation chamber. The chamber was maintained at 15–23 °C, relative humidity was 85–95%, and the photoperiod was 12 h/day with a light density at 15–350 lux for commercial production [72]. Substrate supplementation with an external source of nitrogen is recommended for enhancing the oyster mushroom yield of Pleurotus species. According to Naraian et al., Pleurotus species have a very low nitrogen requirement in its initial substrate colonization [73]. PTR is a tuberous mushroom that produces sclerotium in underneath soil [51]. The species differs from other Pleurotus species cultivation, and it has required casing for high yield fruiting. PTR fruiting body (tuber) and sclerotium are considered a highly nutritional and cheap protein source in Africa [71]. Pleurotus species cultivation has been tested in different bagging systems [7]. Plastic bags were found to yield higher harvest than other methods like trays, racks, and cylindrical containers bagging systems [12,53]. The plastic bags hanged in rows would reduce the contamination level and allow good air circulation [7].

### 3.2. Primordial initiation and biological efficacy

The primordial initiation was generally observed from 16 to 27 d [12,74]. Generally, mature mushrooms are visible within 3–4 d after pinhead formation (Table 4). The mature mushrooms will then be harvested before spraying water. Second and third harvests are obtained after scraping the beds surface to 1–2 cm deep after the first harvest. The entire cropping would be completed in 50–55 d [12]. The biological efficiency of the specific substrates is an essential factor that decides on the suitability of the substrates to cultivate a particular species of mushroom. A total of 3 crops were harvested in the cultivation period about >42 d. The biological efficacy (BE) of Pleurotus species was much lower when it is cultivated on fresh sawdust substrates compared to composted sawdust and bran (rice/wheat) mixture [75]. Rodriguez and Royse reported that PE basidio-carp yields were significantly higher when cultivated using soybean substrates supplemented with basal cottonseed hull or sawdust [48]. The substrates can be processed either by composition or pasteurization, and further addition of supplement substrates can trigger the biological efficacy. A study has reported that the maximum yield of PSC was obtained when cultivated on chopped straw than the wheat straw substrate. Obodai et al. reported that paddy straw was a suitable substrate for PO cultivation [44]. In Pleurotus species, the optimum temperature for primordial initiation and fruiting development varied according to their substrate. PTR and PEO are high temperature tolerant and initiated their primordia at 28–35 °C [30,32]. The yield was reported to be in the range of 438.1–214.6 (g), with a BE of 121.5–51.3% [76] (Table 4).

### 3.3. Postharvest management and processing method

Fresh mushrooms are very perishable and can be preserved only if adequately processed. Postharvest browning of Pleurotus species is related to oxidation of phenolic compounds by polyphenol oxidase, which is the main reason for discoloration [77]. High degree moisture content in fresh mushrooms was a risk to microbial contamination and altered the physicochemical constituents. The best postharvest processing methods for mushrooms is the main reason for discoloration [77]. High degree moisture content in fresh mushrooms was a risk to microbial contamination and altered the physicochemical constituents. The best postharvest processing methods [78]. Dehydration is an effective method of preservation to prevent types of spoilage, except for lipid oxidation. Drying is the most traditional long time preservation technique, especially for mushrooms being used as ingredients for sauces and soups.
Cooling may alter the shelf-life but maybe a useful method in retarding the deterioration process. The instant cooling procedure reduced the field heat and possibly slowed down the metabolic rate [16]. The shelf-life of freshly harvested *Pleurotus* mushroom is reported as 8–11 d at 0 °C or 1–2 d at 20 °C [70]. The minimal processing is a natural and an alternative technique for extending mushrooms self-life (Controlled packing, chemical treatment, blanching, radiation, coating) and conventional processing (e.g., canning and drying) are other popular mushroom preservation techniques [28,78].

In recent years, the mushroom industry is looking forward to value-added products. They are commercially valuable and profitable than fresh mushrooms. Demand for processed mushrooms exists over the past years, and processed mushroom comes in the commercial market as canned, dried, or frozen forms. Other than these categories, the processed *Pleurotus* mushroom also includes instant snacks, pickled, powder, nuggets, and mushroom sauces (Figure 3). Dry mushroom powder forms of PO, PSC, PP, and PE are used as bakery products [79]. In peak production seasons, surplus fresh mushrooms can be processed/converted into value-added products, and this may resort to distress sale [16]. *Pleurotus* mushrooms are used as a health supplement and dietary food due to their health benefits and cholesterol-lowering property.

### 4. Nutritive values of *Pleurotus* species

Mushrooms are appreciated for their proximate composition and nutritional characteristics and are considered to have 28.6–15.4% of proteins, 84.1–61.3% of carbohydrates and 3–33.3% of dietary fiber [80]. Their protein content is higher compared to vegetables, but less compared to meat and milk. *Pleurotus* species are rich sources of proteins and minerals (Na, Ca, P, Fe, and K) and vitamins (Vitamin C and B complex) [81,82]. Additionally, the richness of umami-taste in *Pleurotus* mushrooms may increase food quality [83]. Considerable proportions of carbohydrates consist of dietary fibers, which are rich in fiber (6～28%), especially in the stipe [84] that cannot be easily digested by humans and function essentially as dietary fiber [84]. They contain all the essential amino acids, limiting the sulfur-containing amino acids, cysteine, and methionine [85]. Even though they also contain major lipids, including free fatty acids, mono, di and triglycerides, sterol esters, and phospholipids [86]. *Pleurotus* mushrooms are considered a functional food because of their higher food value, mainly due to high protein content and fat, carbohydrate, minerals, and vitamins [61–77]. Analytical reports on proximate composition showed significant variation from species to species. The active constituents found in *Pleurotus* mushrooms are polysaccharides, dietary fibers, oligosaccharides, triterpenoids, peptides, proteins, alcohols and phenols, and mineral elements such as zinc, copper, iodine, selenium and iron, vitamins, and amino acids [4,14]. These have been found to boost the immune system, have anticancerous properties, and act as anti-hypercholesterolaemic and hepato-protective properties. *Pleurotus* species are excellent food for the people suffering from hypertension and cardiovascular diseases due to high potassium and sodium content [87].

![Figure 3. Postharvest management and processing method of *Pleurotus* species.](image-url)
4.1. Proteins and amino acids

The genus *Pleurotus* can be considered as a good source of palatable proteins, especially for vegetarians. Non-protein nitrogen compounds are in the form of amino acids, chitin, and nucleic acids. The coefficient values most generally range from 3.45 to 4.38 is more appropriate, and the value converts total nitrogen to protein. The mushroom protein assimilability depends mainly on the species, ranging from 9.29 to 37.4 g/100 g of fruit bodies d.w [88]. Tolera and Abera found 28.85% of the protein in fresh PO mushrooms [69]. Protein content in mushrooms runs a wide range based on inherent and agro-climatic factors. Korean *Pleurotus* varieties protein content was around 28.57%, whereas the FAO report showed that the *Pleurotus* species protein was about 30.4% [82,89]. Kortei and Wiafe-kwagyan reported that the protein content of PEO was 24.10% [90]. The protein content level (Table 5). The selection of nitrogen-rich substrates with a supplemented nitrogen source may enhance protein contents [73]. The total amino acid composition in the food is a reliable indicator of quality food, including mushrooms. It is also known that few amino acids contribute to enhancing edible mushrooms taste, making them delicious [90]. The amino acids like tryptophan, cysteine, alanine, and glycine exhibited a synergistic effect with vitamin C and E toward their antioxidant activity. Atri et al. reported that the wild species of PP, PSC, PC, and PF contain rich amino acid profiles [96]. Indeed, the *Pleurotus* species are considered as a good source of protein and amino acid content. *Pleurotus* species also contain high amounts of γ-aminobutyric acid (GABA) and ornithine. GABA is a nonessential amino acid required for brain functioning and mental activity, additionally, the muscle proteins used in the treatment of wasting muscles after illness or post-operative care [83].

4.2. Carbohydrates

Carbohydrates in mushrooms are mainly involved in the structural composition except for sugar-free components, essential in maintaining the high osmotic concentration and serving for the energy release intact with the fast metabolism rate. The *Pleurotus* mushrooms contain large amounts of carbohydrates ranging between 24.95 and 75.88% [45,97]. The polysaccharides and chitin present in mushrooms constitute a major part of mushroom nutrients [88]. The higher amount of celluloid substances, including rich dietary fiber, leads mushrooms as a low-calorie diet with higher therapeutic value for diabetic patients to counteract alimentary ulcers and reduce obesity. In PF and PSC, the carbohydrates level is 42.83 and 39.82%, respectively [25,84]. The ferula (*Pleurotus ferulae*) and white-ling mushrooms (*P. nebrodensis*) contain fewer carbohydrates (47.8–46.2%, respectively) than red (*P.djamor*) (59.9%) and purple (*P.sapidus*) (57.1%) oyster mushrooms [68]. *PTR* contains a high percentage of carbohydrate and low lipid content than other *Pleurotus* species [71]. However, the carbohydrate percentage was all in the range between 34.0–63.3% (Table 5).

4.3. Dietary fiber

Mushrooms have edible dietary fiber and are good sources of essential food compounds that are valuable for human nutrition. The dietary fiber in mushrooms was primarily composed of chitin (a straight-chain (1→4)-β-linked polymer of N-acetyl-glucosamine) and polysaccharide ((1→3)-β-D-glucans and mannans) in their cell walls [98]. Dietary fiber is non-digestible by the human endogenous system, and they exhibit different nutritional and physiological benefits [99]. More specifically, the non-digestible cell wall carbohydrates subunit is considered as a source of dietary fibers. The edible mushrooms provide up to 25% of the dietary fiber recommended dietary intake [100]. The fiber content in pink oyster mushroom, *PDR* (14.60%), was comparable to other oyster mushroom species and

| Strains | Moisture<sup>a</sup> | Protein | Carbohydrate | Fat | Ash | Crude fiber | References |
|---------|----------------------|---------|--------------|-----|-----|-------------|------------|
| PO      | 88.5                 | 32      | 50.9         | 3.1 | 6.1 | 6.2         | [91–93]    |
| PFL     | 91                   | 21.6    | 57.4         | 1.8 | 10.7 | 11.9        | [18,47]    |
| PF      | 87.5                 | 20.56   | 42.83        | 2.31 | 9.02 | 11.5       | [25]       |
| PSC     | 87.0                 | 24.63   | 39.82        | 2.29 | 8.28 | 10.9       | [84]       |
| PC      | 88.9                 | 30      | 42.5         | 3.9 | 7.65 | 20.78       | [3,94]     |
| PE      | 91                   | 11.95   | 39.85        | 7.50 | 4.89 | 28.29       | [46,49]    |
| PP      | 78.8                 | 20.3    | 34           | 2.62 | 7.33 | 9           | [29]       |
| PEO     | 86.81                | 24.10   | 45.59        | 4.73 | 9.84 | 15.91       | [90,95]    |
| PDR     | 79.52                | 35.5    | 44.75        | 1.72 | 5.90 | 14.60       | [12]       |
| PTR     | 87.13                | 22.10   | 63.03        | 1.06 | 2.97 | 10.86       | [71]       |

<sup>a</sup>% of fresh mushroom.

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Table 5. Proximate composition of *Pleurotus* species strains.
winter mushrooms (Flammulina velutipes), which have a fiber content of 22.4 and 31.2%, respectively [12,101]. The fiber content in porcini mushroom, Pleurotus ferulae and Pleurotus nebrodensis (white-ling mushroom) ranged from 11.2 to 15.0% and were relatively low compared with PE (28.29%) and PC (20.78%) [3,49]. Overall, Pleurotus mushrooms which contain an abundant amount of fiber content are like PO (10.21%), PFL (11.9%), PF (29.9%), PSC (10.9%), PP (14.7%), PEO (15.91%), PDR (14.60%), and PTR (10.86%) as reported [12,47,71,86,95,102]. There is a significant variation in the dietary fiber content among the Pleurotus species shown in Table 5. The fruit bodies of PE and PDR contain significant amounts of dietary fibers, and a high variability can also be observed among ten Pleurotus species. So, they are considered a good source of dietary fiber and are associated with blood glucose and cholesterol-lowering activity [103]. PTR can produce a sclerotium with a compact mass of hardened fungal mycelium containing chitin and β-glucans [59]. The edible sclerotium is similar to a commercial source of dietary fiber from a conventional source as legumes [104]. Mushroom dietary fiber and including β-glucans, chitin, and polysaccharide–protein complexes show a wide range of health benefits to humans. Xu et al. demonstrated the cancer effect of polysaccharide–protein complexes derived from PP [105]. On the other hand, other studies demonstrated that β-glucans derived from PTR could induce apoptosis against cancer cells and enhance the immunomodulatory and anti-tumor activities [106]. The high-level intake of Pleurotus mushroom intake can decrease the risk of cancer and other diseases. However, the high variable of dietary fiber in the Pleurotus species is considered a novel food source.

4.4. Lipids

Lipids from mushrooms are highly suitable for humans to the least risk of plaque formation in blood vessels [19]. The crude fat of edible and medicinal mushrooms includes all lipids, free fatty acids, mono, di and triglycerides, sterols, sterol esters, and phospholipids. Fatty acid compositions differ from each fungi species and are an essential component of organelles comprising in fungi about 30–70%. Lavelli et al. made a generalized fat content survey in Pleurotus species reported to be around 0.9–7.5% [83]. The maximum (7.50%) and minimum (1.06%) fat contents were recorded in PE and PTR, respectively [49,71]. In contrast, the average fat content was recorded in PEO (4.73%) and PC (3.9%) (Table 5) [95,107]. The possible reason for this diversified variation in fat content may be the agro-waste used in the cultivation process. Pleurotus species contain low lipids, excellent sources of fatty acids like linoleic acid and oleic acid. The earlier research evidence that Pleurotus species are good candidates for anti-inflammation and hypocholesterolemia in the human diet [19,71,87]. Schneider et al. reported that the PO diet inhibited the accumulation of LDL and VLDL (Low-density lipoproteins and very-low-density lipoprotein) and significantly reduced the total cholesterol (TC) values in humans [108].

4.5. Vitamins and minerals

Pleurotus mushrooms are exceptionally high in folic acid (B9), also known as folic acid, which is nutrients that cannot be produced in the body and must be supplied by the diet. Patil et al. reported the cultivation of PO on the mixture substrates of soybean and wheat straw substrate showed maximum folic acid (0.052 ± 0.02 mg/100g.), thiamin, riboflavin, niacin, and vitamin C content [45]. According to WHO/FAO guidelines, folate is an essential supplement during ovulation, low folate intake during an earlier pregnancy can increase the risk of neural tube defects [109]. The folic acid content in Pleurotus species is described in Table 6. Thiamin and riboflavin content of PEO were 2.23 and 8.97 mg/100g, respectively, while niacin and ascorbic acid content of PFL were 73.3 and 144 mg/100g [110]. PP cultivated on some indigenous fruit trees barks showed a minimal level of B-complex vitamins [111].

Pleurotus mushroom contains most nutritionally essential minerals, such as high potassium, a remarkable level of phosphorus, and low sodium concentration [112]. About 90% of the

| Table 6. Vitamins content in Pleurotus species strains. |
|------------------------------------------------------|
| **Content g/100g dried mushroom**                     |
| **Strains** | **Thiamin (B1)** | **Riboflavin (B2)** | **Niacin (B3)** | **Folic acid (B9)** | **Ascorbic acid** |
| PO         | 0.32            | 0.59               | 8.72            | 0.052              | 12.52             |
| PFL        | 1.46            | 7.10               | 73.3            | 1.22               | 144               |
| PF         | 1.36            | 7.88               | 72.9            | 1.41               | 113               |
| PSC        | 1.75            | 6.66               | 60              | 1.23               | 111               |
| PC         | 0.16            | 0.94               | 22.20           | 0.10               | <1                |
| PP         | 0.68            | 0.26               | 0.48            | –                  | 6.74              |
| PEO        | 2.23            | 8.97               | 66.6            | 1.35               | 92                |

*–* Result not found.
bioavailability of iron (Fe) in the edible mushroom is easily absorbable. The macro element potassium helps maintain normal heart rhythm, fluid balance, blood pressure, nerve function, and blood cholesterol levels. Kikuchi et al. found that Zn content in edible mushroom species ranges between 4.22–7.70 μg/g [113]. The Pleurotus mushrooms are a good source of zinc, contributing to the cause of human nutrition. Iron content in Pleurotus species has been reported in the range of 5.5–13.4. PE contained a high percentage of Fe (0.062%) compared with other Pleurotus species. In PDR, PSC, PO and PF, the potassium and sodium contents were 2218.33; 67.12, 2146; 220, 1950; 270 and 1537; 686, mg/kg, respectively (Table 7). A balance between potassium and sodium will prevent high blood pressure [109,114]. The microelements approved limits for each metal in edible mushrooms were established in many countries. From the nutritional point of view, the trace element selenium is one of the potential sources of nutrients that worked as a cofactor in antioxidants. Bioavailability of selenium from PO, PF, PSC, and PE range between 0.011 and 0.512 mg/100 g [46,101]. The unclear evidence as suggested that selenium may reduce the incidence of cancer when taken in higher doses. Recently, many bioactive compounds were isolated from Pleurotus species, and their pharmacological effects were fully investigated [60]. The regular consumption of Pleurotus species may reduce the cholesterol level and improve immunity in humans.

5. Conclusion

Pleurotus mushroom cultivation is most suitable and profitable in all three climatic conditions like tropical, subtropical, and temperate regions. They may be grown on diversified agro substrates, according to easy availability in different regions of the world. It helps in recycling agricultural wastes and their conversion into protein-rich food. They play an intrinsic part in the forest ecosystem, which may restore and stabilize the forest communities. Mushroom farming is a labor-intensive activity that can improve income generation and provide livelihoods, especially in developing countries. Cultivation techniques for these ten prominent Pleurotus species are well developed and relatively simple, low-cost, and highly profitable than those commonly cultivated mushroom species. Those species contain high protein and low fat in addition to high dietary fiber, folic acid, and potassium might be considered a good source of food. Moreover, Pleurotus species are recognized as a good source of amino acids, which play an essential role as a flavoring agent. This review provides a platform for researchers aiming to develop novel strategies for the cultivation of Pleurotus spp.

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