



Evaluation of Nutritional and Medicinal Values of Edible Wild and Cultivated *Pleurotus ostreatus*[#]

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ABSTRACT

Because of its high nutritional value and pharmaceutical effects, oyster mushroom (*Pleurotus ostreatus* (Jacq. ex Fr.) P. Kumm.) is collected from nature and cultivated in large scale. This therapeutic mushroom is consumed as a functional food or food additive in soups, cereal and dairy products, and commercially used in nutraceuticals and dietary supplements. The mycochemicals including polysaccharides (crude fiber and β -glucans), essential amino acids, ergothioneine, peptides, (glyco)proteins, lectins, phenolic compounds, polyketides (lovastatin), (tri)terpenoids, and enzymes are naturally found in the fruiting bodies and mycelial biomass of *P. ostreatus*. The major bioactive compounds concentration of this mushroom may be increased by modification of the substrate composition and cultivation or postharvest conditions. The goal of this review is to evaluate the results of the studies about the biochemical composition and medicinal properties of edible wild and cultivated *P. ostreatus*. Furthermore, the advanced novel cultivation techniques, biotechnological processes, and postharvest treatments were given in order to increase its nutritional and nutraceutical values.

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Yenilebilir Doğal ve Kültüre Alınmış *Pleurotus ostreatus*'un Besinsel ve Tıbbi Değerlerinin Değerlendirilmesi

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ÖZ

Yüksek besin değeri ve farmasötik özellikleri nedeniyle istiridye mantarı (*Pleurotus ostreatus* (Jacq. ex Fr.) P. Kumm.) doğadan toplanmakta ve büyük miktarda yetiştirilmektedir. Bu terapötik mantar fonksiyonel bir gıda veya gıda katkısı olarak çorbalarda, tahıl ve süt ürünlerinde tüketilmekte ve nutrasötiklerde ve diyet takviyelerinde ticari olarak kullanılmaktadır. Polisakkaritler (ham lif ve β -glukanlar), esansiyel amino asitler, ergotionin, peptitler, (gliko)proteinler, lektinler, fenolik bileşikler, poliketitler (lovastatin), (tri)terpenoidler ve enzimleri içeren mikokimyasallar, *P. ostreatus*'un miselyal biyokütlesinde ve mantar yapısında doğal olarak bulunmaktadır. Bu mantarların başlıca biyoaktif bileşiklerinin konsantrasyonu, substrat kompozisyonu ve kültüre alma veya hasat sonrası koşulların modifikasyonu ile artırılabilir. Bu derlemenin amacı, yenilebilir doğa ve kültüre yapılan *P. ostreatus*'un biyokimyasal bileşimi ve tıbbi özellikleri üzerine yapılan çalışmaların sonuçlarını değerlendirmektir. Ayrıca, besinsel ve nutrasötik özelliklerinin artırılması amacıyla uygulanan ileri yeni yetiştirme teknikleri, biyoteknolojik süreçler ve hasat sonrası işlemlere de değinilmiştir.

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Introduction

Pleurotus species are exclusive wood decomposers. They grow on a wide array of forest and agricultural wastes (Adebayo and Oloke, 2017) in tropical and subtropical areas and are easily cultivated (Chang and Miles, 1989; Kues and Liu, 2000; Kibar and Pekşen, 2008). They colonize on almost all hardwoods such as *Abies*, *Acacia*, *Acer*, *Alnus*, *Betula*, *Carpinus*, *Carya*, *Castanea*, *Laurocerusus*, *Liquidambar*, *Liriodendron*, *Lupinus*, *Magnolia*, *Malus*, *Morus*, *Nyssa*, *Ostrya*, *Pandanus*, *Picea*, *Pistacia*, *Populus*, *Pseudotsuga*, *Quercus*, *Salix*, *Tilia*, *Ulmus*, and *Wisteria* (Anonymous, 2013) and on wood by-products (sawdust, paper, pulp sludge), all the cereal straws, corn and corn cobs, sugar cane bagasse, coffee residues (coffee grounds, hulls, stalks, and leaves), banana fronds, cottonseed hulls, agave waste, soy pulp, and other materials (Ragunathan and Swaminathan, 2003; Sanchez, 2010; Adebayo and Oloke, 2017). Mushrooms of *Pleurotus* spp. (under the class Basidiomycetes) are edible and among the most popular mushrooms worldwide. *Pleurotus* spp. include *P. citrinopileatus* Singer, *P. cystidiosus* O.K. Mill., *P. eryngii* (DC.) Quél., *P. flabellatus* Sacc., *P. florida* Singer, *P. geesteranus* Singer, *P. ostreatus* (Jacq.) P. Kumm., *P. pulmonarius* (Fr.) Quél., *P. sajor-caju* (Fr.) Singer, *P. sapidus* Quél., *P. tuberregium* (Fr.) Singer, *P. ulmarius* (Bull.) P. Kumm., and about 40 different species. They are prolific producers of novel “mycochemicals” (Deepalakshmi and Mirunalini, 2014) and some of them are of a special consideration due to their high nutritional value and medicinal importance (Chang and Miles, 1989; Kues and Liu, 2000; Khan and Tania, 2012; Gomes-Correa et al., 2016). *Pleurotus* species are recognized as dual functional mushrooms as both food and medicine. They include high quality of proteins, vitamins and minerals. Medicinally, they are recommended to obese and diabetes patients because of their low caloric value and very low sugar content without starch (Chang and Buswell, 2003). Furthermore, no case reports about allergy symptoms have been found in the literature (Anonymous, 2013).

Among species of this genus, *P. ostreatus* is the most popularly consumed one due to its taste, flavor, high nutritional value, and medicinal properties. It commonly exists in the mycobiota of Turkey as well as different locations of the world (Sesli and Denchev, 2014; Alkan et al., 2016; Doğan and Kurt, 2016; Akata and Uzun, 2017; Akata et al., 2019). Within the ethnomycological perspective, the edible wild *Pleurotus* species including *P. ostreatus* known as “Kavak mantarı (Poplar mushroom)” are traditionally collected from the forests during the rainy season from March to November and sold in the local markets by the villagers (Kibar and Pekşen, 2008; Alkan et al., 2016; Doğan and Kurt, 2016; Pekşen et al., 2016; Pekşen and Kaplan, 2017). The *Pleurotus* species have many advantages as a cultivated mushroom: rapid mycelia growth, high ability for saprophytic colonization, simple and inexpensive cultivation techniques and several kinds of species, which are available for cultivation under different climatic conditions (Kibar and Pekşen, 2008). In recent years, *P. ostreatus* is commercially cultivated because of its rich mineral contents and medicinal properties, short life cycle, reproducibility in the recycling

of certain agricultural and industrial wastes, and low demand on resources and technology (Yildiz et al., 2002). *Pleurotus* is the second most important cultivated mushroom genus for food purposes throughout the world and Turkey with a share of 27% and 10%, respectively (Royse, 2014; Eren and Pekşen, 2016). In addition, *Pleurotus* mushrooms are preferred because they are suitable for the organic production (Aksu and Uygur, 2005). *P. ostreatus* was reported to have a unique flavor and aromatic properties and considered to be rich in protein, fiber, carbohydrates, vitamins, and minerals. Among the volatile compounds that constitute edible mushroom flavor, 1-octen-3-ol is considered to be the major contributor. *P. ostreatus* is an excellent source of crude fiber (11.8%) and β -glucans (29.5%) and its Amino Acid Score (AAS) meets the nutritional requirements of all essential amino acids for adults (Carrasco-González et al., 2017). *P. ostreatus* is rich in numerous nutritional compounds and various active ingredients, therefore, it has been reported to possess hematological, hypocholesterolic, antidiabetic, antibacterial, anticholesterolemic, antibiotic, antiarthritic, antioxidant, anticancer, antiviral functions, and immunomodulation activities (Cohen et al., 2002; Deepalakshmi and Mirunalini, 2014; Adebayo and Oloke, 2017). A therapeutic effect can be achieved by consuming fresh oyster mushroom fruiting bodies, foodstuffs containing dried oyster mushrooms or supplements with such content (Golak-Siwulska et al., 2018). *Pleurotus* species have a great potential to produce novel value-added products (Wakchaure et al., 2010). The incorporation of dried cultivated *P. ostreatus* into processed foods such as wheat bread (Ndung'u et al., 2015; Oyetao and Oyedeji, 2018), yoghurt (Pelaes et al., 2015), meatball (Süfer et al., 2016), and chips (Doğan et al., 2017) as an additive has been reported to enhance sensory, nutritional, nutraceutical or functional characteristics, in addition, the bioactive compound bioavailability of the products enriched with *P. ostreatus* was studied (Regula et al., 2016). In recent years, some dietary supplements derived from *P. ostreatus* have also been produced and these are commercially available in the market (Reis et al., 2017; Bulam et al., 2018; Üstün et al., 2018). Hence, besides conventional extraction methods, advanced green technologies have also been used to produce higher recoveries of diverse *P. ostreatus* bioactive compounds such as phenolic compounds, ergothioneine, β -glucans, and other polysaccharides, recently (Morales et al., 2018). In addition, some other advanced technologies have been applied to prevent the effects of oxidation and microbial growth on these compounds and increase their capacities in the treatment of some serial diseases as cancer (Mahmoud et al., 2015; 2016). There is no clear suggestion for the daily dose of *P. ostreatus* intake (Khan and Tania, 2012), however there have been some clinical studies on children, adults, and athletes about pharmacological benefits and safe doses of *P. ostreatus* derived products and dietary supplements (Khan and Tania, 2012; Jesenak et al., 2017; Rathore et al., 2017). Besides the aim of consumption as food and dietary supplement, cultivation of *Pleurotus* spp. was reported to provide an eco friendly method for effective disposal of various agro-wastes used as substrate in mushroom

cultivation (Ragunathan and Swaminathan 2003). Furthermore, these mushrooms have been used for the products in terms of medicinal (Kues and Liu, 2000; Golak-Siwulska et al., 2018), cosmetic and cosmeceutical (Taofiq et al., 2016; Wu et al., 2016) purposes, and the production of ligninolytic enzymes that can be used for various biotechnological and environmental applications such as using in bioremediation of resistant pollutants and the bioconversion of agricultural wastes into valuable products for animal feed (Cohen et al., 2002; Akinfemi et al., 2010). In addition, nano polysaccharides (β -glucan) extracted from *P. ostreatus* were expected to have a great potential for use in industrial scale as an emulsifier and a flocculating agent (Mahmoud et al., 2015). Due to growing importance and demand of *P. ostreatus* today, in this review, it has been aimed to review actual information about the studies on the nutritional and medicinal properties of edible wild and cultured *P. ostreatus* in addition to novel cultivation techniques, biotechnological processes, and postharvest treatments to increase its nutritional and nutraceutical values.

Nutritional and Medicinal Values of Wild *P. ostreatus*

When wild *P. ostreatus* was evaluated in terms of nutrition, Akyüz and Kırbağ (2010) determined dry matter, moisture, crude ash, crude protein, crude fat, crude cellulose, organic matter, and nitrogen-free extract as 89.7, 10.3, 12.7-13.7, 27.8-32.8, 0.9-1.3, 10.4-16.2, 76.0 and 26.7-36.8% dw, respectively. Johnsy et al. (2011) detected dry matter (4.87%), carbohydrates (43.40%), lipids (2.47%), protein (37.63%), fibre (4.20%), and ash (10.17%). In another study; moisture, protein, fat, carbohydrate, and ash were reported as 89.69, 16.96, 3.21, 62.27 and 7.25%, respectively (Akata et al. 2012). Turfan et al. (2018) found total soluble protein, total free amino acid, total soluble carbohydrates, glucose, fructose, and sucrose as 33.57, 2.83, 59.89, 8.96, 0.33 and 10.90 mg/g in the wild *P. ostreatus* samples, respectively. Sevindik et al. (2016) detected Na, Zn, Mg, and Fe contents as 125.5, 45.9, 161.9 and 57.1 mg/kg, respectively. Keleş et al. (2017) determined K, Mg, Ca, Mn, and Fe as 5523, 901.7, 454.6, 7.7 and 104.5 mg/kg dw, respectively. Turfan et al. (2018) reported Se content of wild *P. ostreatus* as 2.69 mg/kg. In another study, total protein, vitamin A, vitamin E, and vitamin C were found as 36.25%, 9.62 μ g/g, 998.24 μ g/g and 1,481.25 μ g/g, respectively (Bengu et al., 2019).

From medicinal point of view, Keleş et al. (2011) detected the antioxidant properties of *P. ostreatus* extracts as total phenolic (2686.67 mg/kg), FRAP (2385.71 μ mol/g), DPPH (86.35% at 25 mg/mL), and EC₅₀ (11.07 mg/mL). In Akata et al. (2012) study, *P. ostreatus* showed the most potent free radical scavenging antioxidant activity (96.16%) at 2.72 mg/mL of methanol extract concentration. Vishwakarma et al. (2017) reported the highest antioxidant activity of *P. ostreatus* in all studied protocols as DPPH (0.19 mg/mL), β -carotene bleaching assay (0.36 mg/mL), and H₂O₂ scavenging assay (0.82 mg/mL) in comparison to *P. cystidiosus*, *P. flabellatus*, and *P. florida*. In another study, total phenolics and total flavonoids were indicated as 122.68 and 19.81 mg/g, respectively (Turfan et al., 2018). Bozdoğan et al. (2018) determined total phenolic, flavonoid, and β -carotene

contents of the MeOH extracts of *P. ostreatus* as 15.66 mg/kg, 0.16 mg/kg, 0.02 mg/100 mL, respectively. In addition, at 5 mg/mL, DPPH, RP, H₂O₂, NO and FRAP activities of *P. ostreatus* were found as 17.42%, 0.530 Abs., 73.77%, 33.64%, 0.28 mmol Fe²⁺/L, respectively. Sevindik et al. (2018) detected total antioxidant status (TAS), total oxidant status (TOS), and oxidative stress index (OSI) of edible wild *P. ostreatus* as 2.023 mmol/L, 7.048 μ mol/L and 0.351, respectively.

Nutritional and Medicinal Values of Cultivated *P. ostreatus*

Commercially cultivated mushroom has similar contents of nutritional components compared with wild type mushroom. However, there are some qualitative and quantitative differences in the chemical composition of *P. ostreatus* products depending on the strain, origin, extraction process, and cultivation conditions (Wang et al., 2001; Akyüz and Kırbağ, 2010). Cultivated *P. ostreatus* was characterized by a medium calorific value of 151 J (Manzi et al., 2001) and metabolizable energy content of 242.6 kcal (Khan et al., 2008) in 100 g. Moisture content was detected as 86.5% and protein, lipid, carbohydrate, fiber, and ash were determined as 23.5, 2.6, 39.4, 27.0 and 7.4 g/100 g of dried sample, respectively (Khan et al., 2008). Akyüz and Kırbağ (2010) reported dry matter, moisture, crude ash, crude protein, crude fat, crude cellulose, organic matter, and nitrogen-free extract as 90.0, 10.0, 6.0, 41.6, 0.5, 14.3, 84.0 and 29.6% dw, respectively. Oyetayo and Ariyo (2013) determined amino acid composition as alanine (3.75 g/100 g), arginine (6.30 g/100 g), aspartic acid (4.30 g/100 g), glutamic acid (10.20 g/100 g), glycine (1.65 g/100 g), histidine (1.10 g/100 g), isoleucine (1.26 g/100 g), leucine (2.31 g/100 g), lysine (1.50 g/100 g), methionine (0.53 g/100 g), and cysteine (0.53 g/100 g). Korkmaz and Kırbağ (2014) reported palmitic acid, stearic acid, linoleic acid, oleic acid and docosadyenoic acid on different compost mediums as 22.64-33.06%, 14.08-15.80%, 36.69-41.98%, 18.83-53.50% and 9.79-15.54%, respectively. In another study, total SFA, MUFA, and PUFA were detected as 17.0, 13.6 and 69.4% of total FA, respectively (Reis et al., 2012). Yang et al. (2001) found total soluble sugars (arabitol, glucose, mannitol, myo-inositol, trehalose), total free amino acids, and total 5'-nucleotids as 4.1, 18.2 and 15.8 mg/g dw, respectively. Turfan et al. (2018) determined total soluble protein, total free amino acid, total soluble carbohydrates, glucose, fructose, and sucrose as 75.73-108.66, 4.70-7.43, 222.61-279.32, 33.36-41.90, 0.05-4.71 and 2.85-12.17 mg/g, respectively. Teichmann et al. (2007) reported ergosterol, total sterol, and vitamin D₂ values of dark cultivated *P. ostreatus* as 60.7, 72.4 mg/100 g fw and 0.7 μ g/100 g fw, respectively. Bengu et al. (2019) detected total protein, vitamin A, vitamin E, and vitamin C as 23.18%, 66.86 μ g/g, 654.16 μ g/g and 334.36 μ g/g, respectively. Çağlarırnak (2007) reported texture, moisture, ash, and protein as 0.33 kg/mm², 92.63, 0.63 and 0.92% wb, respectively. In this study, folic acid, vitamin C, thiamin, riboflavin, and niacin were also determined as 9.08 μ g/100 g, 3.38, 0.15, 0.21 and 4.44 mg/100g wb, respectively. Main volatile compounds detected by GS-MS library estimation were nonadecanoic acid (26.28%) and

9,12-Octadecadien-1-ol (24.64%) in the same study. Reis et al. (2012) determined α -tocopherol, γ -tocopherol, and δ -tocopherol as 0.59, 1.49 and 1.64 $\mu\text{g}/100\text{ g fw}$ where β -tocopherol was not detected. In addition, Zn, Fe, P, Ca, Mg, K, and Na amounts were reported as 11.18, 14.80, 998.47, 81.16, 221.9, 2225.00 and 773.67 mg/kg wb, respectively. Sevindik et al. (2016) found Na, Zn, Mg, and Fe contents as 267.9, 134.9, 166.6 and 451.3 mg/kg, respectively. Khan and Tania (2012) informed Se content of *P. ostreatus* as 0.011 mg/100 g dried mushrooms. Synytsya et al. (2008) detected that the fruiting bodies contained small amounts of α -glucans: 3.4-7.9% in the caps and 3.0-7.6% in the stems, respectively. The contents of β -glucans were found as 27.4-39.2% in the caps and 35.5-50.0% in the stems of *P. ostreatus*. In the same study, the highest TDF level (64.8%) was observed in the stems of strain 77, while the lowest TDF level (34.5%) was in the caps of strain L22 *P. ostreatus* related to dry matter. Manzi et al. (2001) determined chitin and β -glucan content of raw commercial *P. ostreatus* samples as 0.32 g/100 g and 139.2 mg/100 g edible weight (dm) and its dietary fibre values as 4.10 (TDF), 3.67 (IDF) and 0.43 (SDF) g/100 g edible weight (dm), respectively. Honda et al. (1999) found an association between high fiber diets and a lower incidence of cardiovascular diseases and large bowel cancers. Synytsya et al. (2009) reported that *P. ostreatus* contained branched β -1,3-1,6-glucan and linear α -1,3-glucan as the major components of cell walls. In addition, potential prebiotic activity of the extracts was also detected by using diverse probiotic strains. Sari et al. (2017) also detected α -glucans and β -glucans as 1.405 and 24.231 g/100 g dm in commercially cultivated *P. ostreatus* samples, respectively. Chen et al. (2012) determined the highest lovastatin, GABA and ergothioneine contents of *P. ostreatus* fruiting bodies from Japan, Korea and Taiwan as 606.5, 23.6 and 1829.4 mg/kg dw, respectively. In another study, caffeic acid, gallic acid, p-hydroxybenzoic acid, myricetin, and ergothioneine contents of *P. ostreatus* were detected as 7.80, 13.0, 1.27, 1.67 $\mu\text{g}/\text{g}$ and 3.78 mg/g in dw (Woldegiorgis et al., 2014). Abidin et al. (2017) indicated that *P. ostreatus* exhibited the best candidate for prevention and treatment of atherosclerosis via hypocholesterolemia due to the fact that it has been proven to contain a large amount of anti-atherosclerotic agents such as ergothioneine, lovastatin, and chrysin.

Kalyoncu et al. (2010) found that the most active species were *P. ostreatus* and *M. giganteus* which showed broad spectrum antimicrobial activity against Gram (+) and Gram (-) bacteria in the grown mycelia extracts. Besides, scavenging capacity of the mycelial extracts (DPPH-6.11%) and equivalent inhibition values of TOC (2.37 $\mu\text{g}/\text{ml}$) were detected for *P. ostreatus* in the same study. Woldegiorgis et al. (2014) determined total phenolics, total flavonoids, antioxidant activity in DPPH scavenging, reducing power, and chelating effect assays as 14.6 mg GAE/g, 1.97 mg CE/g, 1.4, 3.6 and 0.035 EC_{50} , respectively. Yilmaz et al. (2016) reported the total phenolic content as 151.4 mg GAE/100 g and the antioxidant activity as 2508 $\mu\text{mol FeSO}_4 \cdot 7\text{H}_2\text{O}/\text{g}$. In addition, methanolic extracts of *P. ostreatus* showed inhibitory effect against *Klebsiella pneumonia* and *Acinetobacter haemolyticus* bacteria. According to Yilmaz et al. (2017), total phenolic, condensed tannin, FRAP, and

DPPH values of mushroom samples grown on different substrates ranged from 1.07 to 2.67 mg GAE/g, 0.42 to 1.01 CE mg/g, 4.09 to 12.33 $\mu\text{mol FeSO}_4 \cdot 7\text{H}_2\text{O}/\text{g}$ and 4.94 to 15.47 mg/mL, respectively. Adebayo et al. (2018) found that β -carotene-linoleic acid and ORAC assays showed high antioxidant activity, particularly in *P. ostreatus*. Sevindik et al. (2018) detected total antioxidant status (TAS), total oxidant status (TOS), and oxidative stress index (OSI) of cultivated *P. ostreatus* as 1.153 mmol/L, 1.071 $\mu\text{mol}/\text{L}$ and 0.092, respectively. Turfan et al. (2018) determined total phenolics and total flavonoids as 53.68-119.68 and 8.55-11.21 mg/g, respectively. Özdal et al. (2019) detected the highest total phenolic content in *P. ostreatus* hot water extract (9.14 mg/g dry weight of extract). In addition, mycelia extracts from *Pleurotus* species showed antibacterial activity against Gram (-) and Gram (+) plant and human pathogenic bacteria. Since the extract from *P. ostreatus* showed antioxidant and antibacterial properties, it could be used in the formulation of nutraceuticals. Moreover, Sevindik et al. (2016) reported that the ethanolic extracts of the wild and cultured forms of *P. ostreatus* were found to have low antimicrobial activity being more effective on fungal strains, *Candida albicans* and *C. tropicalis* than bacterial strains.

There are various *in vivo*, *in vitro* and clinical study results reporting the medicinal and therapeutic properties of *P. ostreatus* (Khan and Tania, 2012; Patel et al., 2012; Deepalakshmi and Mirunalini, 2014; Correa et al., 2016; Adebayo and Oloke, 2017; Carrasco-González et al., 2017; Piska et al., 2017; Rathore et al., 2017; Golak-Siwulska 2018; Kumar, 2019). Furthermore, the extracts or powder of fruiting bodies or mycelia of *P. ostreatus* have been reported to have anticancer, antitumor, antiviral, antihypercholesterolemic, antihypertensive, antidiabetic, antiobesity, hepatoprotective, hypoglycemic, immunomodulatory, antiaging, antiallergic, antiarthritic, anti-HIV, antineoplastic, antimutagenic, anti-inflammatory, anti-atherogenic, anti-atopic dermatitis, anti-atherosclerotic, antimicrobial, and antioxidant activities and therapeutic properties depending on high and low molecular weight bioactive compounds such as β -glucans, α -glucan, proteins, polysaccharides, proteoglycans, heteroglycan, lectin, lovastatin, chrysin, ergosterol, ergothioneine, pleuran, terpenes, fatty acid esters, and polyphenols.

Cultivation Techniques for Increasing Nutraceutical Value of *P. ostreatus*

The *Pleurotus* fruiting bodies dramatically respond to the chemical composition of the substrate (Carrasco-González et al., 2017). Higher protein values were obtained in *P. ostreatus* depending on different types of substrate, treatment, mycelium, and the weight of the bag used (Pardo et al., 2005; 2007; 2008). Tropical woody substrates of *Pycnanthus ongoleubis* used in cultivation of *P. ostreatus* caused higher mineral, protein, carbohydrate, fat, and dietary fiber contents in addition to all amino acids except phenylalanine in the fruiting bodies (Oyetayo and Ariyo, 2013). Nieto and Chegwin (2013) determined high content of triterpenoids after the cultivation in the mixtures of cereal straws. It has been reported that *Agave sisalana* saline solid waste produced *P. ostreatus* fruiting bodies with higher antioxidant activity (Muthangya et al., 2014).

Kırbağ and Korkmaz (2014) determined the second highest protein content in *P. ostreatus* (36.4%) cultured in growing medium supplemented with wheat stalk. On the other hand, Picornell-Buendía et al. (2016) reported that substrates supplemented with wheat bran and the commercial supplement (Calprozime®) have shown good agronomic performance for *P. ostreatus* and yielded higher protein and ash content.

Mushroom supplementation is an agronomic process which consists of the application of nutritional amendments to the substrates employed for the mushroom cultivation (Carrasco et al., 2018). Besides using substrates with high contents of bioactive compounds, mineral supplementation has also profound effects on *Pleurotus* nutraceutical composition (Carrasco-González et al., 2017). The cultivation on Se-enriched substrates produced fruiting body with increased phenolic content and antioxidant (Gasecka et al., 2015). Culture of *P. ostreatus* on FeSO₄ (0.8 mg/kg) and ZnCO₃ (2.13 mg/kg) enriched substrates produced fruiting body with higher phenolic content but lower antioxidant, whereas the addition of Li reduced phenolic content (Fontes-Vieira et al., 2013). *P. ostreatus* fruiting body cultivated on Se-enriched substrate (0.5 mM) bioaccumulated 63 µg/g Se (Niedzielski et al., 2015). In another study, the highest level of Se absorption was obtained by adding 51 mg/kg of Na₂SeO₃ into the coffee husk substrate and Se bioaccumulation was 58-858 µg Se/g dw in the fruiting bodies (Da Silva et al., 2012). Moreover, Da Silva et al. (2010) showed that Se-enriched mushrooms can be considered as an alternative Se-food source for humans, due to their high bioavailability *in vivo*. Milovanovic et al. (2014) studied Se supplementation as Na₂SeO₃ at concentrations of 5-20 µg/mL into the synthetic medium. Se bioaccumulation was 251-939 µg Se/g dw in the mycelia. *Pleurotus* species cultivation with mineral-enriched substrates is an economic and fast strategy to enhance the nutritional and medicinal properties of fruiting bodies (Carrasco-González et al., 2017).

Post-harvest Treatments for Increasing Nutraceutical Value of *P. ostreatus*

In the past years, diverse post-harvest treatments such as cold storage, modified atmosphere packaging (MAP), gamma and electron beam irradiation, and coating have been investigated in an effort to discover new alternatives for prolongation the shelf life of various mushrooms (Correa et al., 2016). Jaworska et al. (2011) determined that with the exception of samples blanched in water, frozen mushrooms had higher levels of all the investigated amino acids than canned mushrooms. Jaworska et al. (2015) prepared *P. ostreatus* mushrooms (raw or blanched) for consumption by braising with 10% rapeseed oil. They reported higher contents of crude protein, crude fat, total ash, energy, total tocopherols (α , γ , δ), and vitamin E activity on the contrary decreases in B group vitamins, total phenols, total flavonoids, vitamin C, carotenoids, and antioxidant activity after preparation and storage. In addition, blanched mushrooms resulted in lower levels of nutraceuticals and lower values of antioxidant activity than raw mushrooms prepared for consumption. Kortei et al. (2014) studied gamma irradiation between 0.5-2.0 kGy

doses and reported an increase in phenolic, flavonoid, and antioxidant content between 0.5 and 1.0 kGy doses. Huang et al. (2015) studied the effect of UV-B light irradiation on the amount of vitamin D₂ content of edible fruiting bodies and mycelia of five *Pleurotus* spp., and their antioxidant properties. The vitamin D₂ content of irradiated fruiting bodies significantly increased from 0-3.93 to 15.06-208.65 µg/g, vitamin D₂ content in irradiated mycelia of *P. citrinopileatus*, *P. ostreatus*, and *P. salmoneostramineus* mushrooms increased from 0.28-5.93 to 66.03-81.71 µg/g, respectively. The three irradiated mycelium polysaccharide contents decreased in a range from 1.3 to 24.6%. Despite the fact that UV-B irradiation affected the content of ergothioneine, flavonoids and total phenols, the irradiated samples still contained a sufficient amount of these antioxidant components. Tolera and Abera (2017) studied the effects of different levels of osmotic pretreatments prior to drying and different drying methods on nutritional quality of dried mushroom slices and reported that salt concentration increased from 0 to 5 and 10%, the protein content reduced from 26.78 to 25.99 and 24.95% db, the fat reduced from 2.42 to 2.19 and 1.94% db and fiber from 12.82 to 9.41 and 9.01% db, respectively. Contrarily, the ash increased from 9.75 to 10.77 and 12.20% db and the carbohydrate from 38.16 to 43.08 and 45.18% db, respectively. Bakır et al. (2018) investigated the antioxidant capacity of *P. ostreatus* stored in five different temperature environments. The IC₅₀ values of *P. ostreatus* for four different concentrations were found as inh_{+20°C} > inh_{+4°C} > inh_{-10°C} > inh_{-20°C} > inh_{-40°C}, respectively. As a conclusion, the temperature factor of oyster mushroom in the range of -40 to +20 °C storage conditions was directly proportional to the change of antioxidant properties.

Conclusion

P. ostreatus is an edible mushroom with high nutritional and biomedical importance, since it contains a number of bioactive components that also develop its large number of therapeutic functions. It has the potentiality to control many human diseases so the fruiting bodies, mycelia and extracts or concentrates of *P. ostreatus* have been considered as functional food and nutraceutical. Since, most of the therapeutic effects of *P. ostreatus* are based on *in vivo* and *in vitro* studies, more clinical trials are needed to fully realize its potentials. In addition, *P. ostreatus* requires shorter growth time than the other edible mushrooms and a high percentage of the substrate is converted to fruiting bodies which increases the profitability as compared to other mushrooms. Therefore, *P. ostreatus* is an excellent choice for mushroom cultivation with high yield and quality. For this reason, new standardized strategies must be developed to increase the bioavailability, nutritional, and nutraceutical value of *P. ostreatus* during cultivation and after harvest.

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