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REVIEW ARTICLE

Nutraceutical Potential and Processing Aspects of Oyster Mushrooms (Pleurotus Species)

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Abstract: Background: Oyster mushrooms (Pleurotus species) have gained considerable attention of food technologist and nutritionist for their nutraceutical properties. Oyster mushrooms are considered as functional foods due to their richness in functional food ingredients. In recent times, consumption of these mushrooms has increased considerably due to their numerous health benefits. These are potential sources of bioactive components, which are sufficient enough for prevention and treatment of various lifestyle diseases. There are about 200 different species in the genus Pleurotus and these are commonly referred to as “oyster mushrooms”.

Objective: The study aimed to grasp a collective information on nutraceutical and processing aspects of highly perishable but nutritious oyster mushroom

Results: Pleurotus ostreatus is the most commonly consumed species all over the world due to its superior flavor, taste and nutraceutical properties. It acts as a source of natural antioxidants which might be beneficial for human health in preventing or reducing oxidative damage. Nutritionally, these species are rich sources of proteins, dietary fibres, β-glucan, vitamin B-complex, vitamin C and minerals. They contain higher proportions of certain amino acids such as methionine, cystine and aspartic acid than other edible mushrooms. Oyster mushrooms have been reported to possess hypocholesterolemic, anti-bacterial, anti-diabetic, anti-oxidant, anti-arthritis, anti-carcinogenic, hepatoprotective, anti-viral activities and act as natural resources of immunotherapy activities. The use of these mushrooms can overcome the deficiency of protein in the developing countries where there is unavailability or unacceptability of good quality proteins from animal sources because of religious restrictions.

Conclusion: Because of the occurrence of abundant nutritional ingredients and other bioactive components in P. ostreatus, they have a great scope as a potential source for the development of functional or specialty foods for value addition of deficient foods so as to alleviate the nutritional deficiency diseases from society.

Keywords: Bioactive components, nutritional, oyster mushrooms, pharmaceutical, Pleurotus, processing aspects.

1. INTRODUCTION

Mushrooms are widely utilized as vital food products for their major role in human nutrition, health and disease control [1]. Cultivation of edible mushrooms is presently the most cost-effective biotechnology that converts lignocellulosic organic waste into protein-rich food with a decrease in environmental pollution [2]. Oyster mushrooms, the most common species of the genus Pleurotus, have been proved to be the most interesting and most efficient users of straw [3]. There are more than 200 saprophytic species in the genus Pleurotus dispersed worldwide in tropical and temperate environments [4, 5]. These are generally regarded as one of the most popular mushrooms worldwide and have achieved the third position in the production of edible mushrooms, after genus Agaricus and Lentinula [6]. The most common species included in the genus Pleurotus are: P. ostreatus (oyster mushroom), P. citrinopileatus (golden oyster), P. djamor (pink oyster), P. tuber-regium (king tuber oyster), P. eryngii (king oyster), P. nebrodensis (white ferula mushroom, P. pulmonarius (phoenix oyster)), P. cornucopiae (branched oyster mushroom), P. sajor-caju (grey abalone oyster) and P. cystidiosus (abalone mushroom) [4].

Oyster mushrooms are reported to be the rich sources of vitamin B complex, vitamin C and mineral salts required by human body [7]. Due to high nutritional and medicinal properties, short life span, ability to recycle certain agricultural and industrial wastes during cultivation and lower requirement of technology and resources, commercial cultivation of several species of Pleurotus is practiced worldwide [8].

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has been confirmed through investigations that the Pleurotus mushrooms are a rich source of nutritional ingredients and contain various bioactive compounds such as steroids, terpenoids, alkaloids, phenols, nucleotides, and lectins. These bioactive components have been extracted from the fruiting body, culture broth and mycelium of mushrooms and have been reported to possess promising health benefits [9].

Oyster mushrooms are becoming more popular as a health promoter and environmental scavenger in comparison to other medicinal mushrooms thereby leading to advancements in their research and development activities [5]. These can be used to supplement different processed products such as bread and dairy foods due to their ability to improve protein content and quality, along with the valuable health benefits of myco-chemicals or bioactive components present in these mushrooms [10]. The objective of this review is to accumulate existing information about the nutritional, pharmacological and processing aspects of oyster mushroom.

2. NUTRITIONAL COMPONENTS

Oyster mushroom is an important mushroom cultivated throughout worldwide for food purposes. It has a distinctive flavor and aromatic properties and has been found to be rich in fiber, protein, carbohydrates, vitamins and minerals and contains a lower amount of fat [11, 12]. Oyster mushrooms have been reported as an edible and potential resource of medicinal and nutritional components by a large number of researches. The protein content of this mushroom is higher than other foods because of the presence of all nine essential amino acids and these can be used as a substitute for meat diet [13].

Oyster mushrooms are reported to be a potent source of dietary fibers and polysaccharides such as glycogen and other indigestible forms of dietary fibers such as α- and β-glucans, chitin, cellulose and hemicelluloses like galactans, mannans and Xylans [14, 15]. Carbohydrates are present mainly in the form of glycol-proteins or polysaccharides in Pleurotus spp. Polysaccharides include α- and β-glucans, chitin, and other hemicelluloses (e.g. galactans, mannans and xylans.). Various types of glycosidic linkages in glucans include branched (1→3), (1→6)-β-glucans and linear (1→3)-α-glucans. Polysaccharides represent 36 to 60g/100g dry weight of mushrooms whereas, total dietary fiber (mainly chitin) in Pleurotus mushrooms ranges from 10 to 31g per 100g dry weight [16].

Pleurotus species have been reported to be the potent source of vitamins (thiamine, riboflavin, folic acid and niacin) proteins and minerals (Ca, P, Fe, K and Na) [17]. Higher potassium to sodium ratio of these mushrooms makes them perfect food for people suffering from hypertension and heart diseases [18]. However, nutritional composition of Pleurotus may differ according to chemical and physical differences in the growing medium and genetic structure of species [19]. It contains about 17-42% proteins, 37-48% carbohydrates, 0.5-5% lipids, 24-31% fibers, and 4-10% minerals on dry weight basis [20]. The fruiting body of P. ostreatus contains approximately 100 of different bioactive compounds. Fungal cell wall is a rich source of non-starch polysaccharides, such as β-glucan and phenolic compounds such as protocatechuic acid, gallic acid, homo-gentisic acid, rutin, myristin, chrysin, naringin, tocopherol like α-tocopherol and γ-tocopherol, ascorbic acid and β-carotene [21, 22]. Also, they have been found to accumulate a wide range of secondary metabolites, including steroids, terpenes, polyketides and phenolic compounds [23].

Nutritional quality of Pleurotus sajor-caju as a Single Cell Protein (SCP) cultivated in supplemented whey medium has been evaluated and it has been found to contain a large amount of crude protein content (39.25% of dried biomass) with presence of the essential amino acids such as lysine, leucine, threonine and phenylalanine, high ash content (16.2% of dried biomass) and B-vitamins [24]. Genus Pleurotus is well known as an important source of β-glucans, pleuran being the most studied and familiar, has confirmed bioactivity in humans and it is currently used as a natural immune-stimulant (Imunoglukan P4H®) [25-27]. Oyster mushrooms have superior quality proteins and some members of this genus contain complete proteins with all essential amino acids and non-essential amino acids mainly GABA (gamma amino butyric acid), that act as a neurotransmitter and ornithine which act as a precursor for arginine [21].

Pleurotus ostreatus contains lipids in the range of 0.2 to 8g per 100g on dry weight basis. It contains oleic acid (363µg/g dried mushroom), n-6 essential fatty acids linoleic acid (533 µg/g dried mushroom), n-3 essential fatty acid linolenic acid (11.6 µg/g dried mushroom) and arachidonic acid (10.8 µg/g) [14]. It has been reported to contain higher amount of folacine, vitamin B1 and vitamin B3, but a lesser amount of vitamin B12 than other mushrooms. On dry weight basis, it contains thiamin 1.9-2.0, riboflavin 1.8-5.1, niacin 30-65, folate 0.3-0.7 and ascorbic acid 28-35mg/100g [28, 29]. It contains higher content of potassium, copper, magnesium, phosphorous, iron, sodium and zinc [30, 31]. Phytochemical screening of the Pleurotus spp. extract has exposed the presence of saponins, alkaloids, phlobatannins, steroids, terpenes, flavonoids, phenols, anthraquinones and tannins [32, 33]. Therefore, Oyster mushrooms are a rich source of nutraceutical and other bioactive components like phenolic components, flavonoids, alkaloids, tannins, lecithins, lacticase, vitamins and polysaccharides such as β-glucan as well as other components with high antioxidant activities and therapeutic properties (Table 1).

3. PHARMACOLOGICAL PROPERTIES

Mushrooms are progressively becoming popular as a functional food due to their nutraceutical potential. They have a significant importance in our diet due to their high-quality proteins, lower amount of fat, rich sources of minerals such as phosphorus, iron and vitamins including riboflavin, thiamine, niacin, ergosterol and ascorbic acid. Beside their richness in nutritional components, they have also been reported to possess therapeutic effects against various lifestyle diseases such as diabetes, hypertension, cancer, hypercholesterolemia and obesity [34].

The presence of a large number of nutritious components like lectins, polysaccharides, polysaccharide-peptides, vitamins and minerals in oyster mushroom, makes them able to possess potential anticancer, antioxidant, anti-diabetic, immunomodulatory, antimicrobial and anti-hypercholesterolemic properties [35, 36] (Fig. 1).
Table 1. Bioactive components in oyster mushroom and their health benefits.

<table>
<thead>
<tr>
<th>Mushroom</th>
<th>Bioactive Component</th>
<th>Health Benefit</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>P. ostreatus</em></td>
<td>Polysaccharides, lectins, polysaccharide-peptides and polysaccharide-protein complex</td>
<td>Immuno-modulatory effects</td>
<td>[37]</td>
</tr>
<tr>
<td><em>P. geesteranus</em></td>
<td>Polysaccharide-protein</td>
<td>Effective against breast cancer ((MCF-7 cell)</td>
<td>[109]</td>
</tr>
<tr>
<td><em>P. ostreatus, P. cornucopiae</em></td>
<td>Laccase</td>
<td>Inhibition of hepatitis C virus and hepatoma</td>
<td>[59, 110]</td>
</tr>
<tr>
<td><em>P. citrinopileatus</em></td>
<td>Glycoprotein</td>
<td>Effective against Leukemia (U937 cell)</td>
<td>[111]</td>
</tr>
<tr>
<td><em>P. ostreatus</em></td>
<td>Ubiquitin-like protein</td>
<td>Potent inhibitory activity against HIV-1 reverse transcriptase and other antiviral effects</td>
<td>[28] [59]</td>
</tr>
<tr>
<td><em>P. nebrodensis</em></td>
<td>Nebrodeolysin</td>
<td>Induction of apoptosis (lung, breast, hepatoma and cervical)</td>
<td>[112]</td>
</tr>
<tr>
<td><em>P. ostreatus</em></td>
<td>Polysaccharide fraction (PSPO-1a and PSPO-4a)</td>
<td>DPPH and superoxide anion radical scavenging activity</td>
<td>[49]</td>
</tr>
<tr>
<td><em>P. ostreatus</em></td>
<td>β-glucan, vitamin C and phenolic components</td>
<td>Decline of hepatic cell necrosis</td>
<td>[55, 56]</td>
</tr>
<tr>
<td><em>P. ostreatus</em></td>
<td>α-glucan</td>
<td>Preventing colon cancer cell proliferation via initiation of programmed cell death</td>
<td>[61]</td>
</tr>
<tr>
<td><em>P. ostreatus</em></td>
<td>Water soluble proteoglycans</td>
<td>Arresting the growth of tumor cells</td>
<td>[41]</td>
</tr>
<tr>
<td><em>P. ostreatus</em></td>
<td>β-glucan</td>
<td>Reduced the incidence of ACF (Aberrant crypt foci, clusters of abnormal tube-like glands in the lining of the colon and rectum)</td>
<td>[36]</td>
</tr>
<tr>
<td><em>P. djamor, P. eryngii</em></td>
<td>Ribonuclease, Ubiquinone-9</td>
<td>Regulation of proliferative genes by RNase activity, Inhibition of DNA topoisomerase I, and induction of apoptosis</td>
<td>[113, 114]</td>
</tr>
<tr>
<td><em>P. ostreatus</em></td>
<td>Lovastatin</td>
<td>Anti-hypercholesterolemic</td>
<td>[115]</td>
</tr>
<tr>
<td><em>P. ostreatus</em></td>
<td>β-(1,3/1,6) D glucan</td>
<td>Anti-arthritis</td>
<td>[116]</td>
</tr>
<tr>
<td><em>P. ostreatus</em></td>
<td>β-D Glucan (pleuran)</td>
<td>Anti-oxidants</td>
<td>[28, 36, 49, 50]</td>
</tr>
</tbody>
</table>

Fig. (1). Medicinal properties of oyster mushroom.
3.1. Immuno-modulatory Properties

Immuno-modulatory properties along with low cytotoxicity of mushrooms make them an effective remedy in cancer patients exposed to conventional chemotherapy and radiation treatments to build up immunity and decreased toxicity. A large number of bioactive compounds extracted from mushrooms such as polysaccharides, lectins, polysaccharide-peptides and polysaccharide-protein complex have been found to have immuno-modulatory effects [37]. Water extract from fruit bodies and mycelia of

*P. ostreatus* has been shown to play a significant role in increasing the production of reactive oxygen species (ROS) and immuno-modulatory characteristics through immune-competent cells [38].

Mycelia as well as fruiting bodies of Pleurotus species have been reported to possess a number of curative properties like immune-modulatory, immune-stimulatory and anti-inflammatory characteristics [39]. Polysaccharides extracted from *P. ostreatus* have been found to possess immuno-modulatory activity against infectious bursal disease (IBD) in four weeks post-hatching broilers [40]. Three neutral proteoglycans extracted from oyster mushroom (*P. ostreatus*) mycelia have been reported to have immuno-modulatory and anti-cancer properties [41].

3.2. Anti-microbial Properties

The antimicrobial activity of different extracts from *Pleurotus ostreatus* DSM 1833 was evaluated using different extracts such as water infusion of the fresh fruiting bodies, fresh mycelium, dehydrated fruiting bodies and dehydrated mycelium. The extracts were tested against *Escherichia coli*, *Candida albicans* and *Bacillus subtilis* and it was concluded that *B. subtilis* was highly affected with 87.3% inhibition by the extract obtained from dehydrated mycelium. *Candida albicans* was inhibited to the extent of 50.0% by fresh fruiting bodies, dehydrated fruiting bodies and fresh mycelium extracts but the dehydrated mycelium extract inhibited the growth of *E. coli* to the extent of 57.5% [42].

Anti-microbial activity *P. ostreatus* was evaluated against gram-positive bacteria by biosynthesis of silver nanoparticles using oyster mushroom and it was concluded that synthesized silver nanoparticles using *P. ostreatus* showed an utmost zone of inhibition [43]. Methanolic extracts of *Pleurotus species* were found to inhibit the growth of *S. aureus, Bacillus megaterium, Klebsiella pneumoniae, E. coli, C. glabrata, C. albicans and species of Trichophyton and Epidermophyton* to different extents [44]. Tannin and phenolic constituents of *P. ostreatus* make them able to possess antibacterial activity by inhibition of protein synthesis, cell membrane lysis, microbial adhesins and proteolytic enzymes [45]. Also, separation of a novel ubiquitin-like protein from oyster mushrooms has been found to possess potent inhibitory activity against HIV-1 reverse transcriptase [28].

3.3. Anti-inflammatory Properties

The anti-inflammatory effects of *Pleurotus* species are manifested in their capacity to lower dermatitis and arthritis in vivo. It has been reported that aqueous and methanolic extracts of *P. sajor-caju* administered orally (500-1000mg/kg) to rats with Freund adjuvant paw inflammation appreciably reduced arthritis and inflammation [46].

Similar results were observed when β-glucans isolated from *P. ostreatus* were administered orally (1 mg/kg) to arthritis induced rats, and synergistic effects with methotrexate were observed in rats [47]. Furthermore, topical application of ethanolic extracts of *P. eryngii* to mice showed a significant dose-dependent suppression of dermatitis and decreased serum level of IgE and TARC as well as expression of inflammation-related cytokines (TNF-α, INF-γ, IL-4, IL-5 and IL-13) and harsh skin lesions [48].

3.4. Anti-oxidant Activity

Oxidative stress is considered as a primary factor in the development of many lifestyle and degenerative diseases like cancer, diabetes, cardiovascular diseases and hepatotoxicity. Antioxidants present in oyster mushrooms such as phenolic component, vitamins and other flavonoid compounds are helpful in inhibiting oxidative processes.

Oyster mushrooms have been described as a potential source of vitamins and selenium content which are important natural antioxidants in biological systems [1]. The two polysaccharide fractions (PSPO-1a and PSPO-4a) isolated from the fruiting bodies of *P. ostreatus* have been found to exhibit the stronger DPPH and superoxide anion radical scavenging activity. Further, it was found that the polysaccharides PSPO-1a were more effective free-radical scavengers than PSPO-4a [49]. Free radical scavenging and NOS (Nitric oxide synthase) activation characteristics of water-soluble polysaccharides from *P. ostreatus* showed advanced antioxidant properties which might be due to the presence of β-glucan responsible for the antioxidant activity and make this mushroom as a good source for preparation of antioxidant food additives [50]. Immense radical scavenging effects of Petroleum Ether (PE) extract from *P. porrigensat* and *P. florida* against DPPH in comparison with Butylated Hydroxyl Anisole (BHA), Butylated Hydroxyl Toluene (BHT), and Tertiary Butyl Hydroxy Quinone (TBHQ) were observed in another study [51]. The numerous antioxidant activities of Pleurotus spp reported in the literature may be due to high flavonoid, phenol and other antioxidant phytochemicals present in the extracts of these mushrooms [5].

Antioxidant activity of the oyster mushroom Pleurotus ostreatus was tested in male Wistar rats suffering from CCl₄-induced liver damage. When rats with CCl₄-induced hepatotoxicity were exposed to the extract of *P. ostreatus*, the level of the Serum Glutamic Pyruvate Transaminase (SGPT), Serum Glutamic Oxaloacetic Transaminase (SGOT) and serum alkaline phosphatase (SAPL) changed to normal as compared to CCl₄-exposed untreated rats. Therefore, it can be concluded that antioxidants present in the extract of *P. ostreatus* have the potential to alleviate the hepatotoxicity induced by CCl₄ in the rat to a significant level [52].

3.5. Hepatoprotective Effects

Prolonged use of higher doses of some drugs, with exposure to some chemicals or infectious agents can cause liver damage. There is no protective drug available in modern
medicine. Only the herbal medicines having hepatoprotective effects are often used in the treatment of hepatic disorders.

It has been reported that the decrease in the level of serum cholesterol minimizes the risk of atherosclerosis and also improves the condition of the liver. Addition of oyster mushroom (P. ostreatus) to the diet has been found to reduce accumulation of cholesterol in the serum and liver of adult human to a considerable extent [52, 53]. These have also been found to increase the levels of glutathione in the liver by stimulating the activities of glutathione peroxidase and catalase in the liver [54].

Many species of Pleurotus contain bioactive components like β-glucan, vitamin C and phenolic components that increase the activity of antioxidant enzymes such as superoxide dismutase, catalase etc. which are responsible for the decline of hepatic cell necrosis [55, 56]. Hepatoprotective effects of oyster mushroom (Pleurotus sajor-caju) against aflatoxicosis were evaluated in straight run broiler chicken (Vencob strain). Liver damage was evaluated by determination of levels of serum proteins, aspartate aminotransferase, alanine aminotransferase and antioxidant profile which included levels of lipid peroxidation, glutathione peroxidase and superoxide dismutase levels. There was considerable improvement in all the parameters when oyster mushroom extracts were used at 1%, 2.5% and 5% levels indicating the hepatoprotective effect of oyster mushroom [57]. Sulfated polysaccharides from P. eryngii improved at least 2-fold the cell growth inhibition of human lung (A549) and murine hepatoma (H411E) cancer cell lines as compared to nonsulfated polysaccharides [58].

There is neither any protective vaccine nor any efficient drug against Hepatitis C Virus (HCV). A laccase extracted from oyster mushroom (Pleurotus ostreatus) was found capable of preventing replication of HCV after the first dose of treatment at the concentrations of 1.25 and 1.5mg/ml for four days and after the second dose of treatment for another four days at the concentrations of 0.75, 1.0, 1.25 and 1.5mg/ml [59]. A similar study on the hepatoprotective effect of oyster mushroom (Pleurotus Florida) against paracetamol induced liver damage was studied by Sumy et al. [60] in Wistar albino rats.

3.6. Anti-cancer Activity

It has been reported that the aqueous polysaccharide extract from P. ostreatus resulted in anti-proliferative and pro-apoptotic effects on HT-29 colon cancer cells. This effect was attributed to be due to the presence of newly identified low molecular weight α-glucan with promising antitumorogenic properties and found effective in preventing colon cancer cell proliferation via initiation of programmed cell death [61]. The protein extract of P. ostreatus has been reported to exhibit healing efficacy against human colorectal adenocarcinoma cell line (SW 480 cells) and a human monocyte leukemia cell line (THP-1cells) by induced apoptosis in SW 450 cells through Reactive Oxygen Species (ROS) production, glutathione (GSH) depletion and mitochondrial dysfunction [62].

Oyster mushrooms have been reported to possess anti-cancer activity as reported in several animal models. Oral intake of oyster mushrooms in ICR mice treated with N-butyl-N’-butanolnitrosamine, decreased the incidence of urinary bladder carcinoma by 45% in comparison to control mice [63]. Water-soluble proteoglycans from oyster mushrooms were found effective in the treatment of sarcoma180-bearing Swiss albino mice when administered with 5mg/kg for 6 days. Proteoglycans were found to activate NK cells and macrophages in mushroom-treated mice thereby arresting the growth of tumor cells in G0/G1 phase as compared to the control mice [41]. Dietary supplementation of DMH (1, 2-dimethylhydrazine) induced Wistar rats with 10% pleura (a β-glucan from oyster mushrooms), reduced the incidence of ACF (Aberrant crypt foci, clusters of abnormal tube-like glands in the lining of the colon and rectum) by 60%. Also, it reduced the concentration of conjugated dienes by 40% in the colon which are reported to be potential indicators of oxidative stress [36].

3.7. Anti-diabetic and Hypocholesterolemic Effect

Diabetes has become the third serious chronic disease after cancer and cardiovascular diseases. Polysaccharides isolated from oyster mushroom, Astragalus, and Yacon were examined for their inhibitory effects on α-glucosidase as measured by glucose oxidase method. The results concluded that the inhibitory effects of polysaccharides on α-glucosidase were over 40% at the concentration of 0.4mg/ml of polysaccharide. Further, the IC50 value of Astragalus polysaccharide and oyster mushroom polysaccharide was 0.28 and 0.424mg/ml respectively [64]. Hypcholesterolemic effect of oyster mushroom on lipid profile, liver and kidney functions has been reported in rats. In this study, intake of 5% powder of P. ostreatus and P. sajor-caju by rats reduced the plasma total cholesterol level by 37% and 21%, respectively, and triglycerides level by 45% and 24%, respectively, due to the presence of active substance lovastatin [65]. The effect of the king oyster mushroom (Pleurotus eryngii) on insulin resistance and dyslipidemia was evaluated in db/db mice. A diet containing 5% king oyster mushroom was fed to four-week-old db/db mice for 7 weeks. It was concluded that the blood glycated hemoglobin and serum glucose levels in the mushroom fed mice were significantly lower than the control group. Also, it decreased significantly the homeostasis model assessment for insulin resistance (HOMA-IR), triglyceride, total cholesterol and increased High-Density Lipoprotein (HDL)-cholesterol. It was concluded that king oyster mushrooms improved insulin sensitivity and proved to be an effective anti-hyperglycemic and anti-hyperlipidemic agent [66].

Polysaccharide fraction of Pleurotus florida was evaluated for their anti-hyperglycemic capacity. These were highly effective and found to be nontoxic up to 4000mg/kg. Pleurotus florida Polysaccharide (PFP) used at a level of 200 and 400-mg/kg lowered blood glucose concentrations compared to the control group. Also, the concentration of triglycerides, serum cholesterol and glucose and ketones in the urine of animals treated with PFP decreased significantly. Therefore, it can be concluded that FPFs can be used as a potential therapeutic agent against hyperglycemia and hypercholesterolemia associated with diabetes [67]. β-glucans isolated from P. ostreatus mushroom have been found to lower the serum cholesterol concentration [68]. Therapeutic effect of these mushrooms can be enhanced by the utilization of different
4. PROCESSING ASPECTS OF OYSTER MUSHROOM

Because of high respiration rate, metabolic activity and water loss after harvesting, oyster mushrooms are most prone to browning and deterioration. At ambient temperature, they can remain acceptable only up to 1-3 days and at 4°C for 4-7 days. Therefore, processing of oyster mushroom is highly recommended to extend its shelf life [70]. Much work has been done on processing aspects of different mushrooms varieties such as drying [71, 72], irradiation [73], preparation of soup powder [74, 75], pickle [76], chutney [77], bakery products such as bread (Okafor et al. [78]), biscuits [79, 80] and its incorporation with other fruits and vegetables such as tomato-mushroom mixed ketchup [81] and tomato-mushroom mixed soup [82]. Literature available on processing aspects of oyster mushroom is discussed below.

4.1. Development of Value-added Products

Wan Rosli et al. [79] studied the nutrient composition and sensory investigation of butter biscuits incorporated with various levels of grey oyster mushroom (Pleurotus sajor-caju, PSC) powder and found that incorporation of PSC powder up to 4% to replace wheat flour improved flavour and crispiness, increased concentration of dietary fibre, protein and β-glucan but did not affect the fat content of butter biscuit. Prodhan et al. [83] also analyzed the nutrient composition and sensory characteristics of oyster mushroom (Pleurotus sajor-caju, PSC) powder incorporated biscuits. The PSC powder was incorporated at 0, 5, 10 or 15% level to replace wheat flour (WF) for biscuit preparation. Incorporation of 15% PSC powder in biscuits significantly increased the protein content (13.45%) in comparison to control (12.15%). The dietary fibre content of biscuits containing 10% and 15% PSC powder was 4.92 g/100g and 5.07g/100 g, respectively, and was significantly higher than control biscuits (4.47 g/100 g). Results of sensory analysis concluded that biscuits incorporated with 10% PSC powder had the highest scores for all sensory characteristics. It was concluded that incorporation of PSC powder up to 10% level to replace wheat flour increased the contents of protein, dietary fibre and ash content but decreased carbohydrate content of biscuits. Wakchaure et al. [84] developed novel value-added products such as biscuits, jam, soup, pickle, patties and pakodas from fresh/dried oyster mushroom.

Aishah et al. [85] developed three carbohydrate-based products namely Paratha Flatbread (PB), Rice-Porridge (RP), and Conventional Cake (CC) by incorporation of dried Pleurotus sajor-caju (PSC) powder. Products were evaluated for sensory characteristics as well as subjected to proximate analysis. It was concluded that mushroom-based RP incorporated with 6% PSC powder received the highest organoleptic score. Also, the texture of mushroom-based PB was better as compared to the control samples. Cakes were acceptable up to 6% level of incorporation of mushroom powder in wheat flour. It was concluded that PSC powder was successfully incorporated in wheat and rice flour in RP, CC and PB for increasing nutritional value without affecting sensory characteristics of these products.

Saiful Bahri [86] studied the effect of incorporation of oyster mushroom (Pleurotus sajor-caju, PSC) in Herbal Seasoning (HS) on sensory parameters as well as nutritional components. Addition of mushroom powder significantly increased the protein but decreased the fat content of HS. Also, it enhanced colour and viscosity characteristics of the products. Therefore, the incorporation of 40% PSC powder in HS was recommended since it significantly increased nutritional quality and was acceptable to the sensory panel. Singh et al. [87] incorporated pleurotus mushroom powder to wheat flour for the formulations of cake at 0, 5, 10, 15 and 20% level by weight. The cake was subjected to physicochemical and sensory evaluation and it was concluded that addition of powder at 15% level significantly improved nutritional and sensory characteristics. The overall acceptability of the cakes prepared by incorporation of mushroom powder was found to be equal to that of control cake.

Okafor et al. [78] evaluated the physical, nutritional and sensory qualities of wheat bread supplemented with oyster mushroom. Dried mushrooms power was incorporated with wheat flour at 0, 5, 10 and 15% for preparation of bread. Supplementation of oyster mushrooms in wheat bread improved protein, B-vitamins, amino acids and minerals contents of bread. Bread was moderately acceptable only up to 10% level of incorporation of mushroom with wheat flour. Mahamud et al. [88] prepared bread by incorporating mushroom powder from the oyster mushroom. Mushrooms were pretreated with hot water at 100°C for 3 minutes containing 3% salt and 0.01% citric acid. These were then chopped, dried at 33±2°C for 48 hours up to a moisture content of 9-10% and ground to make powder. The powder was then incorporated at 5%, 10% and 15% level to replace wheat flour. It was found that the bread containing 5% mushroom powder was nutritionally superior to bread without mushroom powder and attained the highest consumer acceptability. Hong et al. [89] reported that supplementation of oyster mushroom powder with wheat flour resulted in increased loaf weight but decreased loaf volume in mushroom powder incorporated bread. The increased amount of oyster mushroom powder resulted in rough and coarse crumb texture and dark color of the bread. Sensory evaluation studies concluded that oyster mushroom powder can be incorporated with wheat flour to make an acceptable quality of bread.

Verma et al. [90] developed mushroom powder fortified potato puddings and analyzed their nutritional and sensory characteristics. Products were organoleptically acceptable up to 5% addition of mushroom powder in potato. Potato puddings incorporated with 5% mushroom powder retained a high amount of protein (2.28g) and fibre (0.26g) and good amount of fat (1.36g) and carbohydrate (18.93g) than the control sample.

4.2. Drying as the Most Common Method of Preservation

Dehydration is one of the important preservation methods used for storage of mushrooms, and dehydrated mushrooms
are valuable ingredients in a variety of food formulations such as instant soups, sauces, snacks, pizzas, meat, and rice dishes [91]. Gothandapani et al. [92] studied the quality of oyster mushroom dried by different drying methods and concluded that mushrooms dried by fluidized bed drying condition at 50°C for 80-120 minutes after pretreatment with 0.5 KMS were found to be of better quality than other drying methods. They further found that the treatment with KMS and blanching reduced the nutritive value but enhanced the colour of the mushrooms as compared to sun-dried samples. Also, the storage of mushrooms after pre-treatment at higher concentration (1.5%) of KMS reduced the microbial spoilage. Martinez-Soto et al. [93] utilized different drying techniques such as hot-air drying, vacuum-drying and freeze-drying for drying of oyster mushroom. Mushrooms were subjected to different pretreatments such as blanching or dipping in sodium metabisulphite solution (1 or 5g/L), or dipping in citric acid solution (1 or 5g/L) before drying. It has been found that pretreatment and drying methods affected the time and rate of drying of mushroom. Hot-air and vacuum-dried mushrooms were darker than that of freeze-dried samples. Also, the quality of hot-air and vacuum-dried mushroom after rehydration was inferior to that of freeze-dried samples.

Tiram [94] evaluated the nutritional values of the oyster mushroom dried with different drying techniques such as Low Heat Air Blow (LHAB), Sun Drying (SD) and gas laboratory oven (LO) drying. It was found that mushroom samples dried by LHAB technique contained the highest concentration of both carbohydrates and fats as compared with the other two methods. Besides, SD method retained the highest β-glucan content. It was concluded that LHAB was the most effective method in reducing water activity and retaining nutritional components while both SD and LO were efficient in preserving beta-glucan and dietary fibre contents, respectively. Han et al. [95] determined functional properties, nutritional composition and storage stability of Pleurotus sajor-caju (PSC) powder and found that PSC powder contained significant amounts of protein (22.41%), dietary fibre (56.99%), ash (7.79%), and β-glucan (3.32%) but lower amount of sucrose (0.19%) and fat (2.30%). It also has remarkable functional properties such as water and oil holding capacity, emulsifying activity and swelling capacity. It was concluded that PSC powder can be used as a potential protein and dietary fibre rich ingredient in food industry due to its functional, nutritional, and storage stability properties.

4.3. Modified Atmospheric Packaging

Xiao et al. [96] studied the effect of Modified Atmospheric Packaging (MAP) and different chemical treatments on organoleptic quality, weight loss, cell permeability, texture changes and Polyphenol Oxidase (PPO) activity. MAP along with chemical treatments (CaCl₂ 1.0g/100g, sorbitol 0.05g/100g and citric acid 3.0g/100g) resulted in inhibitory effects on weight loss and cell permeability in mushrooms. They further concluded that active MAP, composed of 1.5% O₂ and 20% CO₂ along with chemical treatments proved to be beneficial in maintaining the quality and shelf-life of oyster mushrooms. Ventura-Aguilar et al. [97] studied the storage life of sliced oyster mushrooms cv. California by pretreatment with two different mixtures of sodium erythorbate and citric acid and their subsequent storage in MAP at 2, 5 and 17°C. Combination of lowest temperature and MAP retained firmness and color as compared to the control samples. It was concluded that the combined treatment of citric acid (1% w/v) + Sodium erythorbate (3% w/v) and storage at 2°C in MAP enhanced the postharvest shelf life of oyster mushrooms.

Kamal et al. [98] studied the effects of respiratory gases on shelf life of fresh oyster mushrooms. Mushrooms were packed in different polymeric packaging materials such as polyurethane trays overlapped with polyvinyl chloride (PVC) microfilm and polypropylene (PP), and kept refrigerated at ambient temperature condition for 12 days. A gas composition as CO₂, O₂, and N₂ concentration was monitored at 3 days intervals for 12 days. The shortest storage period of one day was reported at ambient condition and extended period of 12 days self-life was observed at refrigerated conditions in polypropylene bag or in polystyrene trays.

Jayathunge et al. [99] conducted shelf-life studies on mushrooms packaged in polypropylene, low-density polyethylene and Linear Low-Density Polyethylene (LLDPE) packages after washing with 0.5% Citric Acid (CA) and 0.5% calcium chloride. Suitable packaging material and washing solution were screened out based on off-color and off-odor development in the packages. It was concluded that packaging of mushrooms in 0.015mm packages of LLDPE with 3g of magnesium oxide after washing with 0.5% CA and 0.5% calcium chloride extended the postharvest life at 8°C and 70% RH up to 12 days.

4.4. Preservation by Chemical Treatments

Eissa et al. [100] studied the effect of different thermal and chemical pre-treatments on enzyme activities and quality of smoked mushroom. Mushroom pre-treated with sulphites (SO₂), H₂O₂ and steam blanching before smoking, retained colour and other sensory characteristics along with lower non-enzymatic browning compared with other pre-treatments. It was concluded that chemical and thermal treatments followed by smoking of oyster mushroom reduced enzyme activities and proved to be a suitable technique for preserving mushrooms.

Jafri et al. [101] studied the physicochemical attributes of oyster mushrooms by utilizing three preservation techniques i.e. chemical treatment, Modified Atmosphere Packaging (MAP) and low-temperature storage. Mushrooms treated with a solution of sorbitol (0.05%, w/v), citric acid (3%, w/v) and CaCl₂ (1%, w/v) were stored at modified atmosphere packaging using 10% O₂ and 5% CO₂. These techniques provided better retention of quality characteristics and gained higher sensory scores, resulting in a storage life of 25 days as compared to control samples. Control samples kept under similar packaging conditions with and without chemical treatment spoiled after 15 and 5 days, respectively.

Olotu et al. [102] studied the effect of chemical preservatives on the shelf-life of mushrooms. Mushroom was soaked in preservatives for 10 min, packaged and stored at 4°C for 30 days and analyzed for colour, firmness, weight loss and microbial count. It was concluded that the combined effect of potassium sorbate (0.1%) and citric acid (4%) extended the shelf life of mushroom for 24 days.
4.5. Preservation by Lactic Acid Fermentation

Among various processing options, lactic acid fermentation, the oldest processing technique, is considered as a valuable processing method for maintaining and improving the safety, nutritional value and sensory characteristics of vegetables. It is an anaerobic biological process by which glucose and other six carbon sugars (also, disaccharides of six-carbon sugars, e.g., sucrose and lactose) are converted into cellular energy and the metabolite lactate, in some bacteria and animal cells, such as muscle cells [103].

Liu et al. [104] studied the lactic acid fermentation of three kinds of oyster mushrooms (Pleurotus cornucopiae, Pleurotus sajor-caju and Pleurotus ostreatus) using Lactobacillus pentosus as Lactic Acid Bacteria (LAB). It was observed that LAB controlled pathogenic microorganism, thereby, preventing spoilage of mushroom products. The total concentrations of lactic acid ranged from 3.72mg/ml to 4.49mg/ml on the 18th day in fermented products. It was concluded that L. pentosus can be used as a starter culture in the manufacture of fermented oyster mushrooms.

Zheng et al. [105] used three typical lactic acid fermentation processes (sauerkraut, pickling, and kimchi) for the preservation of King Oyster Mushrooms (Pleurotus eryngii) through inoculation with the starter culture of Lactobacillus plantarum. The final fermented products contained a high population of LAB (>7 Log cfu/g) and prevented the spoilage of product by lactic acid fermentation. It was concluded that lactic acid fermentation was a safe and effective method for long-term preservation of King Oyster Mushroom and was better than the age-old heavy-salting method.

4.6. Preservation by Irradiation

Preservation by irradiation is a cost-effective method to ensure hygienic and sensory quality as well as to enhance shelf-life of mushrooms. Different detection methods such as photo-stimulated luminescence, electron spin resonance and thermo-luminescence for irradiated mushrooms are available, which are validated and proved to be effective.

**Table 2. Effect of different irradiation treatments on oyster mushrooms.**

<table>
<thead>
<tr>
<th>Irradiation Techniques/Treatments</th>
<th>Species</th>
<th>Effects</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>Irradiation with Gamma rays (1-3 kGy)</td>
<td>P. eryngii</td>
<td>1 kGy increased shelf life and quality attributes</td>
<td>[117]</td>
</tr>
<tr>
<td>Illuminated with UV-B with a light intensity maximum at 310-320 nm and 11.5 W/m² for 60 min at 20°C</td>
<td><em>Pleurotus ostreatus</em></td>
<td>Oyster mushrooms accumulated &gt;100μg of vitamin D₂ g-1 dry matter. Concentration of photoproducts such as lumisterol₂, tachysterol₂ and previtamin D₂ increased concurrently.</td>
<td>[118]</td>
</tr>
<tr>
<td>⁶⁰Co gamma-irradiation</td>
<td><em>Pleurotus nebrodensis</em></td>
<td>Low dose of 1.2 kGy can delay significantly the onset of fruit body softening, splitting and browning by 6-9 days in comparison to non-irradiated controls samples</td>
<td>[119]</td>
</tr>
<tr>
<td>Photo-irradiation</td>
<td><em>Pleurotus florida</em></td>
<td>Extracellular synthesis of silver nanoparticles using the aqueous extract of edible oyster mushroom (<em>Pleurotus florida</em>) as a reducing agent</td>
<td>[120]</td>
</tr>
<tr>
<td>Gamma-irradiation</td>
<td><em>P. florida, P. sajor-caju</em></td>
<td>Induced generation of Reactive Oxygen Species (ROS) especially hydroxyl radical (·OH) and peroxyl radical (ROO·), which are capable of inducing lipid peroxidation</td>
<td>[121]</td>
</tr>
<tr>
<td></td>
<td><em>P. rimosus</em> and <em>Ganoderma lucidum</em></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Photo-irradiation</td>
<td><em>Pleurotus florida</em></td>
<td>Synthesis of biofunctionalized gold nanoparticles</td>
<td>[122]</td>
</tr>
<tr>
<td>Irradiation with Ultraviolet-A (wavelength 315-400 nm), Ultraviolet-B (wavelength 290-315 nm), and Ultraviolet-C (wavelength 190-290 nm) for one Hour</td>
<td><em>Lentinula edodes, Pleurotus ostreatus, Agaricus bisporus, and Pleurotus cystidus</em></td>
<td>The highest vitamin D₂ content (184 ± 5.71 μg/g DM) was observed in Oyster mushrooms irradiated with UV-B at 35°C and around 80% moisture.</td>
<td>[123]</td>
</tr>
<tr>
<td>UV-B irradiation</td>
<td><em>Pleurotus spp.</em></td>
<td>Vitamin D₂ content in irradiated mycelia of golden oyster, oyster and pink oyster mushrooms increased from 0.28-5.93 to 66.03-81.71μg/g, respectively.</td>
<td>[124]</td>
</tr>
<tr>
<td>⁶⁰Co gamma-irradiation</td>
<td><em>Pleurotus ostreatus</em></td>
<td>Increased amount of phenolic content, flavonoids, and antioxidant activity of dried <em>Pleurotus ostreatus</em></td>
<td>[125]</td>
</tr>
<tr>
<td>Gamma-irradiation</td>
<td><em>Pleurotus ostreatus</em></td>
<td>Enhanced the hygienic quality, antioxidant potential, extended shelf-life, and preserved nutrients</td>
<td>[126]</td>
</tr>
<tr>
<td>Gamma irradiation, 1 to 6 kGy as physical stress factors</td>
<td><em>Pleurotus ostreatus</em></td>
<td>Resulted in increase in protein, carbohydrates, glucans and growth</td>
<td>[127]</td>
</tr>
</tbody>
</table>
Safety aspects of irradiated mushrooms are well acknowledged providing evidences that this technique is quite safe with some added advantages [106]. Various studies extracted from literature about the irradiation treatments applied to different species of oyster mushrooms and their significant effects on nutritional, organoleptic and enhancement of shelf-life are depicted in Table 2.

UV-C irradiation (200-280 nm) is a non-thermal disinfection method used for a wide variety of fruits and vegetables. This technique is characterized by the low cost of equipments and maintenance and lower energy requirements [107]. Wang et al. [108] studied the viability of UV-C treatment for enhancing the shelf-life of oyster mushrooms. Mushrooms were packaged with LDPE pouches and subjected to treatment with 4.0 kJ/m² Ultraviolet-C (UV-C) radiation. These were then stored at 4°C for 15 days. Mushrooms treated with UV-C resulted in the decreased rate of changes in soluble solid content, color, soluble protein, increased activity of catalase (CAT). Also, there was a considerable increase in Phenylalanine Ammonia-lyase (PAL) activities, lower tissue electrolyte leakage, high potential ability for surface decontamination and better overall quality as compared to untreated oyster mushrooms. It was concluded that the shelf life of oyster mushrooms can be extended by application of UV-C treatment.

CONCLUSION AND FUTURE PROSPECTS

It can be concluded that oyster mushroom is a novel edible mushroom with great nutritional and therapeutic significance. The presence of a large number of bioactive components such as β-glucan, ascorbic acid, lectins, phenolic components, antioxidants and polysaccharide-protein complex makes them suitable to be used as an ingredient for nutritional enrichment of mushroom-based functional foods. These mushrooms can provide significant support against malnutrition and nutrition deficiency diseases. There is large production of these mushrooms during their season but a major portion of their produce gets perish due to lack of processing techniques. So, there is an immense need for development of processing technologies for such nutritious but highly perishable foods. Also, bioactive constituents present in these mushrooms can be extracted and encapsulated so as to achieve maximum therapeutic benefits. There is also a need to study the effects of P. ostreatus both in vitro and in vivo conditions and clinical trials are required to fully understand its nutraceutical potentials.

CONSENT FOR PUBLICATION

Not applicable.

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CONFLICT OF INTEREST

The author declares no conflict of interest, financial or otherwise.


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