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EDIBLE MUSHROOM *Pleurotus ostreatus* (OYSTER MUSHROOM) – ITS DIETARY SIGNIFICANCE AND BIOLOGICAL ACTIVITY

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ABSTRACT

Pleurotus ostreatus (Jacq.) P. Kumm. (*Basidiomycota*) – known as the oyster mushroom – is a mushroom species distributed on all continents, except for Antarctica. Since World War I it has been commercially cultivated on a large scale. *Pleurotus ostreatus* is a valuable mushroom of dietary importance. It is rich in primary and secondary metabolites and chemical elements of physiological significance. One hundred grams of fresh fruiting bodies contains 15% of the recommended daily intake of vitamin C, 40% of niacin, riboflavin, and thiamin, and 0.5 mg of vitamin B_{12}. This species is also characterized by a high content of oleic acid (40%), linolenic acid (55%), and substances responsible for decreasing serum cholesterol levels. High contents of lovastatin, an approved hypolipidemic drug, and pleuran, an immunomodulating polysaccharide, have been found in fruiting bodies of this species. It exhibits antiatherosclerotic, hypoglycemic, antioxidant, anticancer and immunomodulatory properties. Due to its wide spectrum of biological activities, *P. ostreatus* is considered a medicinal mushroom. Fruiting bodies and extracts of *P. ostreatus* have found applications in the treatment of civilization – related diseases, especially diabetes, arteriosclerosis and cancer. It is also a potential source of active ingredients in cosmetics and topically applied preparations.

Key words: antioxidant activity, edible mushroom, lovastatin, *Pleurotus ostreatus*, pleuran

INTRODUCTION

Pleurotus ostreatus (Jacq.) P. Kumm. (*Basidiomycota*), of the *Pleurotaceae* family, comes from China; however, nowadays it is distributed all over the world, except for the north-west Pacific because of the arctic climate. Cultivation methods were developed in Germany during World War I and then successfully applied on a large scale. This was the result of the search for new food sources, due to the problem of hunger in Germany. In Poland, *P. ostreatus* is a common species [Wojewoda 2003]. It is found on dead wood and the branches of living trees, especially hornbeam (*Carpinus* sp.), beech (*Fagus* sp.), willow (*Salix* sp.), poplar (*Populus* sp.), birch-tree (*Betula* sp.) and common walnut (*Juglans regia*). This species produces different sized, grouped fruiting bodies in forms resembling a colony of oysters, which has led to its given name of *P. ostreatus*. Fruiting bodies are pink, gray to dark-brown in color, ranging in a size from 4 to 15 cm (phot. 1). In the wild, its fruiting bodies generally appear in autumn (October–November); however, they may be encountered during mild winters or in early, warm springs.

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Pleurotus ostreatus is tolerant of low temperatures; however, it has high requirements for light – under low light conditions it does not produce fruiting bodies, or produces very small ones [Wojewoda 2003].

After *Agaricus bisporus*, *P. ostreatus* is the second most cultivated edible mushroom and is of great eco-nomic significance [Sanches 2010]. It has a bittersweet smell of benzaldehyde, characteristic of anise and almonds [Beltran-Garcia et al. 1997]. In many countries, especially in Asia it is considered a delicacy, while in the Czech Republic and Slovakia it is used as a meat substitute [Beltran-Garcia et al. 1997, Sanches 2010]. It is cultivated on straw – its mycelium is able to decompose, transform and use biomass of lignin-cellulose crop wastes for growth. This process also has significance in the waste biodegradation.

This species has been shown to have a higher yield and growth than other cultivated mushrooms. In recent decades a great increase in the international cultivation of *P. ostreatus* has been noted due to its significant tolerance of varied agroclimatic conditions [Sanches 2010, Kholoud et al. 2014].

Phot. 1. *Pleurotus ostreatus* Jacq.: Fr. Kummer (*Basidiomycota*) – Oyster mushroom. Photo by B. Muszyńska

Because of its contents of nutrients readily digestible proteins, mineral salts, vitamins, and compounds with potent pharmacological activities, e.g. lovastatin and pleuran, *P. ostreatus* is an important mushroom species of dietary and medical significance [Anandhi et al. 2013, Muszyńska et al. 2014, Caz et al. 2015].

Chemical composition of *Pleurotus ostreatus*

The content of water in fresh fruiting bodies of *Pleurotus ostreatus* is about 80–90% similarly as is the case in other fungi. From 100 g mushrooms, 10 g dried fruits are obtained, consisting of 2.5 g proteins and about 5 g polysaccharides – mainly starch and others such as mannitol and trehalose. The mycelium of *P. ostreatus* has great nutritional value, due to the presence of high contents of amino acids (arginine, alanine, glutamine, glutamic acid). In 100 g of fresh mycelia, the level of vitamin C represents 15% of the recommended daily intake for humans. This species also contains 0.1–0.2 g fats, including oleic acid (40%), linolenic acid (55%), and other compounds with hypocholesterolemic action. The content of saturated fatty acid is relatively small (≈10%) [Barros et al. 2007].

One of the most important compounds in *P. ostreatus* is lovastatin – an approved to market drug used in the treatment of dyslipidemia – that acts as an inhibitor of HMG-CoA reductase (see section Biological activity of *P. ostreatus*). The highest content of lovastatin was found in lamella of mature mushrooms [Gunde-Cimerman and Cimerman 1995]. Variable amounts of lovastatin have been demonstrated for samples coming from different countries. *Pleurotus ostreatus* from Japan, Taiwan, and Korea contained 606.5 μg, 216.4 μg and 165.3 μg (per 1 g of DW), respectively. Variability was found in terms of the contents of ergothioneine (944.1–1829 μg) and γ-aminobutyric acid – GABA (0–23.6 μg) [Shin-Yu et al. 2012]. Ergothioneine was detected in cultivated *P. ostreatus* from Ethiopia: 3.78 $\mu g\ g^{-1}$ DW [Woldegiorgis et al. 2014]. Ergothioneine is a compound which is accumulated in animal cells and tissues exposed to oxidative stress; however, it is not endogenously synthetized. It plays a role not only as an antioxidant, but also as an antimutagenic, chemo- and radioprotective agent; hence, ergothioneine is considered a compound suitable in adjuvant treatment of strokes, neurodegeneration, and cardio-vascular diseases [Cheah and Halliwell 2012, Woldegiorgis et al. 2014].

In extracts of *P. ostreatus*, researchers have found an active β-glucan, named pleuran (fig. 1). This is characterized as an immunomodulatory agent with potential applications in the treatment of cancer, infections and immune system disorders [Devi et al. 2013, Devi et al. 2015]. Pleuran is a branched polysaccharide, where the backbone consists of β-D-glucopyra- nosyl linked with (1→3) bonds, and every fourth residue is substituted with a (1→6) D-glucopyranosyl group [Karácsonyi and Kuniakb 1994]. It may contain a small proportion of interior (1→6) and (1→4)-linked residues [Karácsonyi and Kuniakb 1994, Fričová and Koval'akovà 2013].

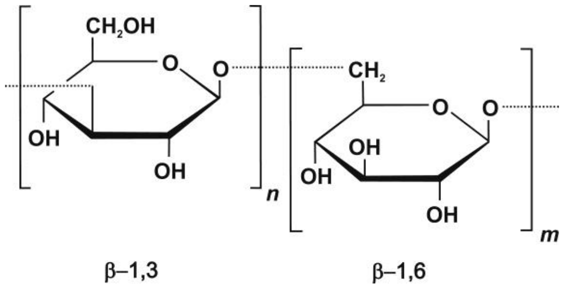

Fig. 1. Pleuran (author: B. Muszyńska)

High contents of mineral salts of potassium, phosphorus, calcium, iron, copper, zinc, magnesium, and selenium were found in mycelium of *P. ostreatus* [Muszyńska et al. 2016]. Because of the increasing interest in mushrooms as a source of macro- and microelements, release of zinc ions (ZnII) from *P. ostreatus* to artificial gastric juice was determined, using differential pulse anodic stripping voltammetry. The amount of zinc in artificial saliva, stomach and intestinal juices, ranged from 1.88 to 2.83 mg, 1.14–8.33 mg and 0.41–1.59 mg per 100 g DW, respectively. Fruiting bodies of *P. ostreatus* after thermal processing imitating culinary preparation were extracted in artificial saliva, stomach and intestinal juices, with zinc contents recorded at: 0.41–4.95 mg, 0.78–2.65 mg and 2.18–2.23 mg per 100 g DW, respectively [Muszyńska et al. 2016]. This microelement is essential for protein synthesis, insulin homeostasis and it acts as a cofactor of over 300 enzymes, including superoxide dismutase. Its beneficial effects in humans include acceleration of wound healing, an increase in mental performance, protection of eye yellow macula against degeneration, and antioxidant properties [Powell 2000, Noormagi et al. 2010].

Among the phenolic content, flavonoids and phenolic acids have been found. The phenolic compounds include p-hydroxybenzoic, synapic, ferulic, p-coumaric, protocatechuic, vanillic, caffeic, gallic, homogentisic, gentisic and chlorogenic acids [Meetoo et al. 2007, Kim et al. 2008, Alam et al. 2010, Palacios et al. 2011, Muszyńska et al. 2013, Woldegiorgis et al. 2014, Gąsecka et al. 2015], while the flavonoids are myricetin, naringenin, hesperidin, formononetin and biochanin A [Alam et al. 2010, Palacios et al. 2011, Muszyńska et al. 2013, Woldegiorgis et al. 2014, Gąsecka et al. 2015]. The levels of individual phenolic compounds are presented in Table 1. Indicated differences among studies may be the result of different methods of mushroom cultivation, preparation, extraction, as well as geographical variability [Alam et al. 2010, Palacios et al. 2011, Muszyńska et al. 2013, Woldegiorgis et al. 2014, Gąsecka et al. 2015].

Biological activity of *P. ostreatus*

Pleurotus ostreatus showed a wide spectrum of biological activities, among which its hypoglycemic properties are the focus of great interest. *Diabetes mellitus* is one of the most common civilization – related diseases, found both in developed and developing countries. Prognoses indicate an increase in morbidity from year to year [Meetoo et al. 2007]. Disease progress is associated with a number of complications, and leads to premature death.

Many drugs are available on the market, including compounds derived from nature, e.g. the recently approved dapagliflozin, an inhibitor of sodium-glucose transport proteins (SGLT2), the structure of which is based on phlorizin. Diabetes leads to cholesterol and lipid disorders; therefore, patients are forced to treat both ailments [Nesto 2008]. *Pleurotus ostreatus* has shown beneficial activity not only in regulating blood glucose levels, but also in regulating lipid metabolism. This direction of action is associated with the occurrence in this species of many types of compounds; however, one of the most significant chemicals found is lovastatin, a drug approved in 1987 by the US Food and Drug Agency (FDA) and widely used in current therapy of dyslipidemia. It acts as an inhibitor of HMG-CoA reductase an enzyme catalyzing reduction of 3-hydroxy-3-methylglutaryl-CoA to mavalonate, which is the first step in the endogenous synthesis of cholesterol. Inhibition of this process leads to a decrease in cholesterol levels in the liver, and an increase in the expression of low-density lipoproteins receptors on hepatocyte cell membranes and finally to an increased uptake of LDL and VLVD from the blood [Bobek et al. 1995]. Beyond their specific mechanism of action, statins exhibited pleiotropic activities, including stabilization of artherosclerotic plaque, as well as anti-inflammatory, anticoagulation, immunomodulatory, and proliferation inhibiting properties with regard to the muscle of the left ventricle [Kavalipati et al. 2015]. However, this hypolypidemic effect in *P. ostreatus* is also associated with the presence of other compounds, e.g. chrisin, or β-glucans [Anandhi et al. 2013, Caz et al. 2015]. Another aspect of *P. ostreatus* activity is its antioxidant action – this mushroom beneficial effects in preventing progression of diabetes associated with oxidative stress [Kaneto et al. 2010].

Table 1. Levels of phenolic compounds in *P. ostreatus* mycelium

Phenolic compound	Levels of phenolic compounds among various studies					
	Woldegiorgis et al. [2014][b]	Muszyńska et al. [2013][a]	Kim et al. [2008][b]	Palacios et al. [2011][b]	Gąsecka et al. [2015][b]	Alam et al. [2010][b]
p-hydroxybenzoic acid	1.25	3.60	–	4.69	5.30	–
Synapic acid	–	2.11	–	–	–	–
Cinnamic acid*	–	1.09	–	–	–	–
Ferulic acid	–	0.46	–	20.16	30.00	–
p-coumaric acid	–	–	–	11.15	10.54	–
Protocatechic acid	–	2.52	18.0	19.32	0.21	81.0
Vanillic acid	–	–	–	–	0.34	–
Caffeic acid	7.80	–	–	–	0.35	–
Gallic acid	13.00	–	7.0	290.34	–	36.0
Homogentisic acid	–	–	16.0	629.86	–	–
Chlorogenic acid	–	–	19.0		–	27.0
Genstisic acid	–	–	–	292.62	–	–
Myricetin	1.67	–	21.0	21.99	–	–
Naringenin	–	–	9.0	–	0.18	10.0
Hesperidin	–	–	–	–	–	10.0
Formononetin	–	–	–	–	–	14.0
Biochanin A	–	–	–	–	–	10.0

[a] – mg/kg DW, [b]– μg/g DW; * precursor of selected phenolic compounds

Hypoglycemic activity of *P. ostreatus*. The hypoglycemic activity of *P. osteratus* has been indicated in alloxan-induced diabetic mice. Ethanolic extract decreased serum glucose levels, improved serum lipid profiles and kidney function [Ravi et al. 2013]. In the same model of diabetes hypoglycemic activity was shown in rats fed with 500 mg kg^{-1} BW of pulverized mushroom. The efficacy of *P. ostreatus* was comparable with that of metformin or glibenclamide [Jayasuriya et al. 2012]. *Pleurotus ostreatus* also showed hypoglycemic, hypolipidemic and hypocholesterolemic activity in streptozotocin-induced diabetes in rats [Chorváthová et al. 1993]. Hypoglycemic efficacy has also been studied in human subjects. In 27 patients with diabetes and hypertension, 3-month supplementation of their diet with 3 grams of pulverized mushroom lead to a decrease in diastolic and systolic blood tension, fasting glucose level and glycated hemoglobin (HbA_{c1}) [Choudhury et al. 2013]. Pulverized *P. ostreatus* administered to 22 healthy persons decreased fasting glucose levels after oral administration of glucose solution. A similar effect was observed in 14 diabetic patients, with an additional increase in insulin level. No changes in aminotransferase activity or creatinine levels were observed, indicating a lack of hepato- or nephrotoxic effects [Jayasuriya et al. 2015]. The hypoglycemic activity of *P. ostreatus* seems to be a complex process including many mechanisms. Jayasuriya et al. [2015] showed a potential for decreasing glycemia using *P. ostreatus* through the activation of glucokinase, stimulation of insulin burst and inhibition of glycogen synthase kinase, resulting in increased glycogen synthesis [Jayasuriya et al. 2015].

Hypolipidemic activity. This mode of action of *P. ostreatus* has been studied in *in vitro* models in rodents, as well as human subjects. In rats with Triton WR-1339-induced hypercholesterolemia, ethanol extract at a daily dose of 500 mg kg^{-1} BW (body weight) significantly decreased levels of VLDL, LDL, total cholesterol, aminotransferases, lactate dehydrogenase and glucose, while increased HDL levels were observed. [Anandhi et al. 2013]. A diet consisting of 10% of dried mushroom, and 1% cholesterol in rabbits resulted in a 65% decrease in serum cholesterol levels and in some animals prevented the development of arteriosclerosis, compared to the control group not supplemented with *P. ostreatus* [Bobek and Galbavý 1999]. In similar studies including rats, results were analogous [Bobek et al. 1998, Alam et al. 2009]. In studies comparing the hypolipidemic effect of three *Pleurotus* species (*P. ostreatus*, *P. sajorcaju*, and *P. florida*), *P. ostreatus* showed the greatest influence on the reduction of blood cholesterol and triglyceride levels, while in terms of decreasing LDL/HDL ratios, *P. sajor-caju* was shown to be more effective [Alam et al. 2009].

An eight-week study with 20 patients treated with an antiretroviral therapy, which results in dyslipidemia as an adverse drug reaction, showed a positive effect of *P. ostreatus* on lipid profiles only in 3 subjects [Abrams et al. 2011]. However, Slovak researchers indicated a significant effect from six-week supplementation with pulverized *P. ostreatus* on a decrease in triglyceride and cholesterol levels in dyslipidemic patients, without any influence on HDL [Kajaba et al. 2008]. A study including 30 diabetics showed the influence of a diet containing mushrooms on a decrease in glucose, triglyceride and cholesterol levels, combined with an additional blood pressure reducing effect. No adverse effects to the liver or kidneys were recorded [Khatun et al. 2007].

The mechanism of hypolipidemic activity of the species probably also includes many pathways. One possible mechanism is the decrease in lipid absorption from the gastrointestinal tract and their increased elimination with feces [Bobek et al., 1996 Alam et al. 2009]. Another mechanism is connected with the inhibition of HMG-CoA reductase by lovastatin [Bobek et al. 1995]. More recent studies have also shown an influence on the expression of genes associated with lipid metabolism. Water extract standardized for β-glucans affected expression of Dgat1 (diglyceride acyltransferase), which is responsible for triglyceride synthesis. In mice fed with *P. ostreatus*, an increase in the expression of genes associated with lipid transport and β-oxidation was observed [Sato et al. 2011].

Antineoplastic activity. Among the medical properties of mushrooms, anticancer activity is one of the most attractive for researchers. Neoplasms pose a significant civilizational – related problem and also leading causes of death globally. Currently available drugs and therapy methods have not been sufficiently efficacious to significantly decrease the scale of problem; therefore, the search for novel anticancer agents is continuing [Siegel et al. 2015]. From fungi, numerous compounds of varied chemical structures have been isolated and shown to possess desirable activities. Special significance is given to polysaccharides which are used in standard cancer treatments, e.g. lentinan [Patel and Goyal 2012]. The anticancer activities of *P. ostreatus* extracts and isolated compounds have been studied in cancer cell lines and in rodents.

Water extract from pulverized *P. ostreatus* showed cytotoxicity against colon cancer cell lines COLO-205, with an IC_{50} of 81.2 μg ml^{-1}. The extract decreased cells ability to form colonies and alters cell migration. Moreover, induction of apoptosis is observed in treated cells. Increased expression of Bax, caspases 3 and 9, and decreased Bcl-2 mRNA was recorded, and cell cycle arrest in G_0/G_1 was demonstrated [Arora and Tandon 2015]. Intracellular and extracellular polysaccharide fractions from *P. ostreatus* cultivated in conditions of submerged fermentation, inhibited proliferation of HCT15, HCT116, RL 95, and SW480 cell lines [Silva et al. 2012]. *Pleurotus ostreatus* glucan at a dose of 10 mg and 20 mg per kg BW decreased Sarcoma 180 tumor weight by 37.30 and 51.89%, respectively. No cytotoxic effect has been observed *in vitro*; however, increased proliferation of lymphocytes has been shown, which may suggest immunomodulatory properties as a possible antitumor mechanism [Devi et al. 2013]. Devi et al. [2015] also showed a lack of direct cytotoxic activity of glucan against Dalton lymphoma cells. Glucan exhibited immunomodulating activity via an increase in lymphocytes proliferation and macrophages activation. Also, induction of the cytotoxicity of NK cells and macrophages against cancer cells was shown. After administration of glucan to Dalton lymphoma bearing mice at a dose of 20 mg kg^{-1} BW, inhibition of tumor growth was more than 70%. Moreover, rodents' survival period increased. An isolated polysaccharide POMP2 of 29 kDa molecular weight inhibited proliferation and migration and decreased formation of colonies in BGC-823 cell lines, while in rodents it significantly decreases the volume and weight of tumors [Cao et al. 2015]. Sarangi et al. isolated three fractions of proteoglycans, which at a concentration range of 10–100 μg ml^{-1} showed cytotoxicity against sarcoma 180 cells. Also, an *in vitro* immunomodulatory effect was observed – proteoglycans increased proliferation of splenocytes and activated macrophages and NK cells [Sarangi et al. 2006].

A protein complex isolated from *P. ostreatus* induced apoptosis in a SW480 cell line, probably through induction of oxidative stress, decrease in intracellular glutathione and a reduced mitochondrial transmembrane potential [Wu et al. 2011]. A protein complex obtained by another method at a dose of 5 and 10 mg per kg BW reduced growth of tumors in Dalton lymphoma bearing mice by 35.68 and 51.43%, respectively. The above doses also prolonged survival time of Dalton lymphoma, Sarcoma-180 and B16F0 melanoma bearing mice. Induction of apoptosis was observed in cancer cells [Maiti et al. 2011]. Another isolated antineoplastic compound was dimeric lectin, with subunit weights of 40 and 41 kDa. Lectin prolonged survival time of mice bearing sarcoma S-180 and hepatoma H-22 and reduced tumor growth [Wanga et al. 2000 a].

The results of studies have shown the anticancer potential of *P. ostreatus*. This species contains various compounds with such modes of action; however, especially important is the presence of polysaccharides, including glucans, and proteins with cytotoxic properties. Divergent results in terms of the cytotoxic activity of glucans *in vitro* suggest a different mechanism of action of *P. ostreatus* glucans. Some may act by direct cytotoxicity against cancer cells, while others may act by immunomodulatory properties, or by a combination of both mechanisms.

Antioxidative properties. A significant role in the pathogenesis of diabetes and its complications, arteriosclerosis, carcinogenesis, neurodegeneration diseases and numerous other diseases, is played by oxidative stress induced by reactive oxygen species (ROS). Therefore, antioxidants are considered as compounds preventing disease development, but also with potential application in treatment [Hajhashemi et al. 2010]. Extracts from *P. ostreatus* showed direct antioxidant properties comparable with BHA and vitamin C, in DPPH, ABTS, FRAP, and β-carotene bleaching assays [Yim et al. 2010, Arbaayah and

Kalsom 2013, Chowdhury et al. 2015]. Elbatrawy et al. [2015] examined antioxidant properties of seven extracts obtained with seven different solvents. In DPPH assays, the most potent was the water extract. This mode of action of *P. ostreatus* may be related to the content of phenolic acids, flavonoids, vitamins C and E and polysaccharides [Yim et al. 2010, Muszyńska et al. 2013]. However, the species not only has the capacity for direct interaction with ROS, but can also increase the activity of antioxidant enzymes in tissues. In rats treated with ethanolic extract of *P. ostreatus* an increase in CAT (catalase) gene expression was observed in the liver and kidneys with a simultaneous decrease in protein carbonylation in these organs [Jayakumar et al. 2010]. Ethanol extract in diabetic rats increased the activity of catalase, superoxide dismutase (SOD), and glutathione peroxidase (GPx). It also increased the levels of vitamins C and E in the liver and decreased the levels of malonyldialdehyde (MDA) [Tahrani and Barnett 2010]. Antioxidative and protective effects were also observed against toxicity induced by paracetamol (acetaminophen) and carbon tetrachloride [Jayakumar et al. 2006, 2008, Naguib et al. 2014].

Antiviral activity. There are individual reports concerning the antiviral properties of *P. ostreatus*. Wanga and Ng [2000 b] found a protein of 12.5 kDa which inhibited translation in a rabbit reticulocyte lysate system and exhibited low ribonuclease activity toward yeast tRNA. It also inhibited reverse transcriptase of the HIV-1 virus. Laccase (58 kDa) inhibited entry of the hepatitis C virus into peripheral blood cells and hepatoma cells. The enzyme also had the ability to inhibit intracellular replication of a virus in HepG2 cell lines at concentration of 0.75–1.5 mg ml^{-1} [El-Fakharany et al. 2010]. Water extract of *P. ostreatus* exhibited antiviral activity against influenza A virus and herpes simplex virus 2 in cell lines infected by the above viruses [Krupodorova et al. 2014]. Water and methanolic extracts as well as polysaccharide fractions were assayed against HSV-1. The highest potency was shown by a polysaccharide fraction with IC_{50} = 4.80 μg mL^{-1}. Acyclovir was used as a reference agent, and this showed IC_{50} = 0.20 μg mL^{-1} [Santoyo et al. 2012].

Antimicrobial activity. Water and alcoholic extracts from *P. ostreatus* mycelium have been used in studies on antimicrobial activities against numerous types of microbes. The highest potency was shown by water extract, especially towards fungi: *Candida albicans*, *Cryptococcus humicola*, *Trichosporon cutaneum*; and bacteria: *Staphylococcus aureus* and *Escherichia coli*. In the extract the active substance was identified as 3-(2-aminophenyl-1-thio)-3-hydroxypropanoic acid, with MIC 30 μg mL^{-1} and 20 μg mL^{-1}, against fungi and bacteria, respectively [Younis et al. 2015]. Methanolic extract from *P. ostreatus* mycelium showed activity against gram positive and negative bacteria with MIC in the range of 4–8 μg mL^{-1} [Chowdhury et al. 2015]. Ethanolic extract inhibited growth of *Pseudomonas aeruginosa*, *Salmonella typhi*, *Staphylococcus aureus*, *Bacillus subtilis*, *Bacillus atropaeus*, *Klebsiella pneumoniae*, and at the highest potency level: *Candida albicans* and *Agrobacterium tumifaciens* [Ahmad et al. 2014]. Additionally, ergosterole peroxide was found in the species and it acted in a toxic manner against *Trypansomona cruzi* as well as showed an amoebicidal effect [Ramos-Ligonio et al. 2012, Meza-Menchaca et al. 2015]. The above studies clearly showed the antimicrobial activity of *P. ostreatus*; however, due to the high concentration required to achieve it this effect seems to be insignificant in comparison to other activities of the mushroom.

***Pleurotus ostreatus* as a potential source of active substances in cosmetology.** The fruiting bodies are a good source of previously described antioxidant and antiageing substances such as ergothioneine, phenolic compounds, and the indole compounds: melatonin, serotonin, and selenium [Kim et al. 2008, Muszyńska et al. 2011, Mohamed and Farghaly 2014, Woldegiorgis et al. 2014]. The selenium content was determined to be 58.24 mg kg^{-1} and 100.31 mg kg^{-1} in fresh and dried mushroom, respectively [Mohamed and Farghaly 2014]. Moreover, fifty five aroma compounds were demonstrated in mycelium, including 27 esters, 9 ketones, 7 thiols, 5 alcohols, 4 terpenoids, 2 phenols and 1 aldehyde [Mohamed and Farghaly 2014]. Aroma compounds play a significant role in the perfume industry and in the production of cosmetics. A cream based on β-glucans, and also containing pleuran, showed a significant positive effect in supportive therapy for atopic dermatitis in a study including 105 patients, of which 80 completed the trial [Jesenak et al. 2015].

CONCLUSIONS

Pleurotus ostreatus is a widely distributed and cultivated mushroom with medical significance. It has a broad spectrum of biological activities and potential in the prevention and treatment of diseases. Due to the high contents of mineral salts and organic compounds essential for humans, it is of great dietary importance. Its activity is especially confirmed in decreasing blood sugar levels and in improving lipid profiles. Additionally, it has antiatherogenic, antioxidant and antineoplastic properties. Detection of lovastatin and pleuran in fruiting bodies has partially explained its activities and has made this species a significant mushroom of medical and nutritional value.

REFERENCES

Abrams, D.I., Couey, P., Shade, S.B., Kelly, M.E, Kamanu-Elias, N., Stamets, P. (2011). Antihyperlipidemic effects of *Pleurotus ostreatus* (oyster mushrooms) in HIV-infected individuals taking antiretroviral therapy. BMC Complement. Altern. Med., 11, 60.

Ahmad, N., Mahmood, F., Khalil, S.A., Zamir, R., Fazal, H., Abbasi, B.H. (2014). Antioxidant activity via DPPH, gram-positive and gram-negative antimicrobial potential in edible mushrooms. Toxic. Ind. Health., 30, 826–834.

Alam, N., Amin, R., Khan, A., Ara, I., Shim, M.J., Lee, M.W., Lee, U.Y., Lee, T.S. (2009). Comparative effects of oyster mushrooms on lipid profile, liver and kidney function in hypercholesterolemic rats. Mycobiology, 37, 37–42.

Alam, N., Yoon, K.N., Lee, K.R., Shin, P.G., Cheong, J.C., Yoo, Y.B., Shim, J.M., Lee, M.W., Lee, U.Y., Lee, T.S. (2010). Antioxidant activities and tyrosinase inhibitory effects of different extracts from *Pleurotus ostreatus* fruiting bodies. Mycobiology, 38, 295–301.

Anandhi, R., Annadurai, T., Anitha, T.S., Muralidharan, A.R., Najmunnisha, K., Nachiappan, V., Thomas, P.A., Geraldine, P. (2013). Antihypercholesterolemic and antioxidative effects of an extract of the oyster mushroom, *Pleurotus ostreatus*, and its major constituent, chrysin, in Triton WR-1339-induced hypercholesterolemic rats. J. Physiol. Biochem., 69, 313–323.

Arbaayah, H.H., Kalsom, Y.U. (2013). Antioxidant properties in the oyster mushrooms (*Pleurotus spp*.) and split gill mushroom (*Schizophyllum commune*) ethanolic extracts. Mycosphere, 4, 661–673.

Arora, S., Tandon, S. (2015). Mushroom extracts induce human colon cancer cell (COLO-205) death by triggering the mitochondrial apoptosis pathway and Go/G1-Phase cell cycle arrest. Arch. Iran. Med., 18, 284–295.

Barros, L., Baptista, P., Correia, D.M., Casal, S., Oliveira, B., Ferreira, I.C.F.R. (2007). Fatty acid and sugar compositions, and nutritional value of five wild edible mushrooms from Northeast Portugal. Food Chem., 105, 140–145.

Beltran-Garcia, M.J., Estarron-Espinosa, M., Ogura T. (1997). Volatile compounds secreted by the oyster mushroom (*Pleurotus ostreatus*) and their antibacterial activities. J. Agric. Food Chem., 45, 4049–4052.

Bobek, P., Galbavý, S. (1999). Hypocholesterolemic and antiatherogenic effect of oyster mushroom (*Pleurotus ostreatus*) in rabbits. Nahrung, 43, 339–342.

Bobek, P., Hromadová, M., Ozdín, L. (1995). Oyster mushroom (*Pleurotus ostreatus*) reduces the activity of 3-hydroxy-3-methylglutaryl CoA reductase in rat liver microsomes. Experientia, 51, 589–591.

Bobek, P., Ozdín, L., Galbavý, S. (1998). Dose- and time-dependent hypocholesterolemic effect of oyster mushroom (*Pleurotus ostreatus*) in rats. Nutrition, 14, 282–286.

Bobek, P., Ozdín, L., Kuniak, L. (1996). Effect of oyster mushroom (*Pleurotus ostreatus*) and its ethanolic extract in diet on absorption and turnover of cholesterol in hypercholesterolemic rat. Nahrung, 40, 222–224.

Cao, X.Y., Liu, J.L., Yang, W., Hou, X., Li, Q.J. (2015). Antitumor activity of polysaccharide extracted from *Pleurotus ostreatus* mycelia against gastric cancer *in vitro* and *in vivo*. Mol. Med. Rep., 12, 2383–2389.

Caz, V., Gil-Ramírez, A., Largo, C., Tabernero, M., Santamaría, M., Martín-Hernández, R., Marín, F.R., Reglero, G., Soler-Rivas, C. (2015). Modulation of cholesterol-related gene expression by dietary fiber fractions from edible mushrooms. J. Agric. Food. Chem., 63, 7371–7380.

Cheah, I.K., Halliwell, B. (2012). Ergothioneine; antioxidant potential, physiological function and role in disease. Biochim. Biophys. Acta. Mol. Basis Dis., 1822, 784–793.

Chorváthová, V., Bobek, P., Ginter, E., Klvanová, J. (1993). Effect of the oyster fungus on glycaemia and cholesterolaemia in rats with insulin-dependent diabetes. Physiol. Res., 42, 175–179.

Choudhury, M.B.K., Rahman, T., Kakon, A.J., Hoque, N., Akhtaruzzaman, M., Begum, M.M., Choudhuri, M.S.K., Hossain, M.S. (2013). Effects of *Pleurotus ostreatus* on blood pressure and glycemic status of hypertensive diabetic male volunteers Bangladesh. J. Med. Biochem., 6, 5–10.

Chowdhury, M.M.H., Kubra, K., Ahmed, S.R. (2015). Screening of antimicrobial, antioxidant properties and bioactive compounds of some edible mushrooms cultivated in Bangladesh. Ann. Clin. Microbiol. Antimicrob., 14, 8–13.

Devi, K.S., Behera, B., Mishra, D., Maiti, T.K. (2015). Immune augmentation and Dalton's Lymphoma tumor inhibition by glucans/glycans isolated from the mycelia and fruit body of *Pleurotus ostreatus*. Int. Immunopharmacol., 25, 207–217.

Devi, K.S., Roy, B., Patra, P., Sahoo, B., Islam, S.S., Maiti, T.K. (2013). Characterization and lectin microarray of an immunomodulatory heteroglucan from *Pleurotus ostreatus* mycelia. Carbohydr. Polym., 94, 857–865.

Elbatrawy, E.N., Ghonimy, E.A., Alassar, M.M., Wu, F.S. (2015). Medicinal mushroom extracts possess differential antioxidant activity and cytotoxicity to cancer cells. Int. J. Med. Mushrooms, 17, 471–479.

El-Fakharany, E.M., Haroun, B.M., Ng, T.B., Redwan, E.R. (2010). Oyster mushroom laccase inhibits hepatitis C virus entry into peripheral blood cells and hepatoma cells. Prot. Pept. Lett., 17, 1031–1039.

Fričová, O., Koval'aková, M. (2013). Solid-State 13C CP MAS NMR spectroscopy as a tool for detection of (1→3, 1→6)-β-D-Glucan in products prepared from *Pleurotus ostreatus*. ISRN Anal. Chem., vol. 2013, Artic. ID 248164, 4 p.

Gąsecka, M., Mleczek, M., Siwulski, M., Niedzielski, P. (2015). Phenolic composition and antioxidant properties of *Pleurotus ostreatus* and *Pleurotus eryngii* enriched with selenium and zinc. Eur. Food Res. Technol., 226, 737–743.

Gunde-Cimerman, N., Cimerman, A. (1995). *Pleurotus* fruiting bodies contain the inhibitor of 3-hydroxy-3-methylglutaryl-coenzyme a reductase-lovastatin. Exp. Mycol., 19, 1–6.

Hajhashemi, V., Vaseghi, G., Pourfarzam, M., Abdollahi, A. (2010). Are antioxidants helpful for disease prevention? Res. Pharm. Sci., 5, 1–8.

Jayakumar, T., Sakthivel, M., Thomas, P.A., Geraldine, P. (2006). Antioxidant activity of the oyster mushroom *Pleurotus ostreatus*, on CCl(4)-induced liver injury in rats. Food Chem. Toxic., 44, 1989–1996.

Jayakumar, T., Thomas, P.A., Isai, M., Geraldine, P. (2008). *Pleurotus ostreatus*, an oyster mushroom, decreases the oxidative stress induced by carbon tetrachloride in rat kidneys, heart and brain. Chem. Biol. Interact., 176, 108–120.

Jayakumar, T., Thomas, P.A., Isai, M., Geraldine, P. (2010). An extract of the oyster mushroom, *Pleurotus ostreatus*, increases catalase gene expression and reduces protein oxidation during aging in rats. Chin. J. Integr. Med., 8, 774–780.

Jayasuriya, W.J., Suresh, T.S., Abeytunga, D., Fernando, G.H., Wanigatunga, C.A. (2012). Oral hypoglycemic activity of culinary-medicinal mushrooms *Pleurotus ostreatus* and *P. cystidiosus* (higher basidiomycetes) in normal and alloxan-induced diabetic Wistar rats. Int. J. Med. Mushrooms, 14, 347–355.

Jayasuriya, W.J., Wanigatunge, C.A., Fernando, G.H., Abeytunga, D.T., Suresh, T.S. (2015). Hypoglycaemic activity of culinary *Pleurotus ostreatus* and *P. cystidiosus* mushrooms in healthy volunteers and type 2 diabetic patients on diet control and the possible mechanisms of action. Phytother. Res., 29, 303–309.

Jesenak, M., Urbancek, S., Majtan, J., Banovcin, P., Hercogova, J. (2015). β-Glucan-based cream (containing pleuran isolated from *Pleurotus ostreatus*) in supportive treatment of mild-to-moderate atopic dermatitis. J. Derm. Treat., 10,1–4.

Kajaba, I., Simoncic, R., Frecerova, K., Belay, G. (2008). Clinical studies on the hypolipidemic and antioxidant effects of selected natural substances. Bratisl. Lek Listy, 109, 267–272.

Kaneto, H., Katakami, N., Matsuhisa, M., Matsuoka, T. (2010). Role of reactive oxygen species in the progression of type 2 diabetes and atherosclerosis. Mediat. Inflamm., ID 453892, doi: 10.1155/2010/453892.

Karácsonyi, Š., Kuniakb, Ľ. (1994). Polysaccharides of *Pleurotus ostreatus*: Isolation and structure of pleuran, an alkali-insoluble β-d-glucan. Carbohydr. Polym., 24, 107–111.

Kavalipati, N., Shah, J., Ramakrishan, A., Vasnawala, H. (2015). Pleiotropic effects of statins. Indian J. Endocrinol. Metab., 19, 554–562.

Khatun, K., Mahtab, H., Khanam, P.A., Sayeed, M.A., Khan, K.A. (2007). Oyster mushroom reduced blood glucose and cholesterol in diabetic subjects. Mymens. Med. J., 16, 94–99.

Kholoud, M.A., Nahla, A.B., Nadia, S., Al., K. (2014). Cultivation of oyster mushroom *Plerotus ostreatus* on date-palm leaves mixed with other agro-wastes in Saudi Arabia. Saudi J. Biol. Sci., 21, 616–625.

Kim, M.Y., Seguin, P., Ahn, J.K., Kim, J.J., Chun, S.C., Kim, E.H., Seo, S.H., Kang, E.Y., Kim, S.L., Park, Y.J., Ro, H.M., Chung, I.M. (2008). Phenolic compound concentration and antioxidant activities of edible and medicinal mushrooms from Korea. J. Agric. Food Chem., 56, 7265–7270.

Krupodorova, T., Rybalko S., Barshteyn, V. (2014). Antiviral activity of Basidiomycete mycelia against influenza type A (serotype H1N1) and herpes simplex virus type 2 in cell culture. Virol Sin., 29, 284–290.

Maiti, S., Mallick, S.K., Bhutia, S.K., Behera, B., Mandal, M., Maiti, T.K. (2011). Antitumor effect of culinary-medicinal oyster mushroom, *Pleurotus ostreatus* (Jacq.: Fr.) P. Kumm., derived protein fraction on tumor-bearing mice models. Int. J. Med. Mushrooms, 13, 427–440.

Meetoo, D., McGovern, P., Safadi, R. (2007). An epidemiological overview of diabetes across the world. Br. J. Nurs., 16, 1002–1007.

Meza-Menchaca, T., Suárez-Medellín, J., Del Ángel-Piña, C., Trigos, Á. (2015). The amoebicidal effect of ergosterol peroxide isolated from *Pleurotus ostreatus*. Phytother. Res., 29, 1982–1986.

Mohamed, E.M., Farghaly, F.A. (2014). Bioactive compounds of fresh and dried *Pleurotus ostreatus* mushroom. Int. J. Biotech. Well. Indus., 3, 4–14.

Muszyńska, B., Komendacki, P., Kała, K., Opoka, W. (2014). L-Tryptophan and its derivatives in edible mushrooms species. Med. Inter. Rev., 103, 82–86.

Muszyńska, B., Zając, M., Kała, K., Opoka, W., Rojowski, J. (2016). Thermal processing can affect zinc availability in some edible mushrooms. LWT – Food Sci. Technol., 69, 424–429.

Muszyńska, B., Sułkowska-Ziaja, K., Ekiert, H. (2011). Indole compounds in some culinary – medicinal higher basidiomycetes from Poland. Int. J. Med. Mushrooms, 13, 449–454.

Muszyńska, B., Sułkowska-Ziaja, K., Ekiert, H. (2013). Phenolic acids in selected edible basidio-mycota species: *Armillaria mellea*, *Boletus badius*, *Boletus edulis*, *Cantharellus cibarius*, *Lactarius deliciosus* and *Pleurotus ostreatus*. Acta Sci. Pol. Hortorum Cultus, 12, 107–116.

Naguib, Y.M., Azmy, R.M., Samaka, R.M., Salem, M.F. (2014). *Pleurotus ostreatus* opposes mitochondrial dysfunction and oxidative stress in acetaminophen-induced hepato-renal injury. BMC Complement. Altern. Med., 14, 494.

Nesto, R.W. (2008). LDL cholesterol lowering in type 2 diabetes: What is the optimum approach? Clin. Diab., 26, 8–13.

Noormagi, A., Gavrilova, J., Smirnova, J., Tougu, V., Palumaa, P. (2010). Zn(II) ions co-secreted with insulin suppress inherent amyloidogenic properties of monomeric insulin. Biochem. J., 430, 511–518.

Palacios, I., Lozano, M., Moro, C., D'Arrigo, M., Rostagno, M.A., Martínez, J.A., García-Lafuente, A., Guillamón, E., Villares, A. (2011). Antioxidant properties of phenolic compounds occurring in edible mushrooms Food Chem., 128, 674–678.

Patel, S., Goyal, A. (2012). Recent developments in mushrooms as anti-cancer therapeutics: a review. Biotech, 2, 1–15.

Powell, S.R. (2000). The antioxidant properties of zinc. J. Nutr., 130, 1447–1454.

Ramos-Ligonio, A., López-Monteon, A., Trigos, A. (2012). Trypanocidal activity of ergosterol peroxide from *Pleurotus ostreatus*. Phytother. Res., 26, 938–943.

Ravi, B., Renitta, R.E., Prabha, M.L., Issac, R., Naidu, S. (2013). Evaluation of antidiabetic potential of oyster mushroom (*Pleurotus ostreatus*) in alloxan-induced diabetic mice. Immunopharm. Immunotoxic., 35, 101–109.

Sanches, C. (2010). Cultivation of *Pleurotus ostreatus* and other edible mushrooms. Appl. Microbial. Biotechnol., 85, 1321–13377.

Santoyo, S., Ramírez-Anguiano, A.C., Aldars-García, L., Reglero, G., Soler-Rivas, C. (2012). Antiviral activities of *Boletus edulis*, *Pleurotus ostreatus* and *Lentinus edodes* extracts and polysaccharide fractions against *Herpes simplex* virus type 1. J. Food Nutr. Res., 51, 225–235.

Sarangi, I., Ghosh, D., Bhutia, S.K., Mallick, S.K., Maiti, T.K. (2006). Anti-tumor and immunomodulating effects of *Pleurotus ostreatus* mycelia-derived proteoglycans. Int. Immunopharm., 6, 1287–1297.

Sato, M., Tokuji, Y., Yoneyama, S., Fujii-Akiyama, K., Kinoshita, M., Ohnishi, M. (2011). Profiling of hepatic gene expression of mice fed with edible japanese mushrooms by DNA microarray analysis: comparison among *Pleurotus ostreatus*, *Grifola frondosa*, and *Hypsizigus marmoreus*. J. Agric. Food Chem., 59, 10723–10731.

Shin-Yu, C., Kung-Jui, H., Yun-Jung, H., Li-Ting, W., Jeng-Leun, M. (2012). Contents of lovastatin, g-aminobutyric acid and ergothioneine in mushroom fruiting bodies and mycelia. Food Sci. Technol-Leb., 47, 274–278.

Siegel, R.L., Miller, K.D., Jemal, A. (2015). Cancer statistics, 2015. CA Can. J. Clin., 65, 5–29.

Silva, S., Martins, S., Karmali, A., Rosa, E. (2012). Production, purification and characterisation of polysaccharides from *Pleurotus ostreatus* with antitumour activity. J. Sci. Food Agric., 92, 1826–1832.

Tahrani, A.A., Barnett, A.H. (2010). Dapagliflozin: a sodium glucose cotransporter 2 inhibitor in development for type 2 diabetes. Diab. Ther., 1, 45–56.

Wanga, H., Gaoa, J., Ng, T.B. (2000 a). A new lectin with highly potent antihepatoma and antisarcoma activities from the oyster mushroom *Pleurotus ostreatus*. Biochem. Biophys. Res. Comm., 276, 587–593.

Wanga, H.X., Ng, T.B. (2000 b). Isolation of a novel ubiquitin-like protein from *Pleurotus ostreatus* mushroom with anti-human immunodeficiency virus, translation-inhibitory, and ribonuclease activities. Biochem. Biophys. Res. Comm., 276, 587–593.

Wojewoda, W. (2003). Checklist of Polish Larger Basidiomycetes. W. Szafer Institute of Botany, Polish Acad. of Sci. Kraków.

Woldegiorgis, A.Z., Abate, D., Haki, G.D., Ziegler, G.R. (2014). Antioxidant property of edible mushrooms collected from Ethiopia. Food Chem., 157, 30–36.

Wu, J.Y., Chen, C.H., Chang, W.H., Chung, K.T., Liu, Y.W., Lu, F.J. Chen, C.H. (2011). Anti-cancer effects of protein extracts from *Calvatia lilacina*, *Pleurotus ostreatus* and *Volvariella volvacea*. Evid. Based Compl. Alternat. Med., ID 982368, 10 p.

Yim, H.S., Chye, F.Y., Tan, C.T., Ng, Y.C., Ho, C.W. (2010). Antioxidant activities and total phenolic content of aqueous extract of *Pleurotus ostreatus* (cultivated oyster mushroom). Mal. J. Nutr., 16, 281–291.

Younis, A.M., Wu, F.S., El Shikh, H.H., (2015). Antimicrobial activity of extracts of the oyster culinary medicinal mushroom *Pleurotus ostreatus* (higher basidiomycetes) and identification of a new antimicrobial compound. Int. J. Med. Mushrooms, 17, 579–590.