The Potential Use of Mushrooms β-Glucans in the Food Industry

Eleftheriadis Eleftherios, Mavraganis G. Vassilis and Israilides Cleanthes*

Institute of Technology of Agricultural Products, NAGREF-ELGO DEMETER, Athens, Greece

Abstract: Many edible mushrooms are considered as "functional" foods having immunomodulatory and anticancer properties. The ability of mushrooms to exert biological effects and modulate immune functions is due to the presence of bioactive compounds with most important the polysaccharides β-glucans. Β-glucans are found in bacteria, fungi and plants and act on several immune cell receptors resulting in both innate and adaptive response. The incorporation of β-glucans in various foods and animal feed has the potential of creating novel "functional" food products, with many health benefits to human and animal nutrition.

Keywords: Mushrooms, β-glucans, Functional food.

In our modern Western way of life most of today's 'food' is processed and unhealthy. Our supermarkets are full of convenient packaged foods that are appealing to our taste but because most of these foods are lacking of natural nutrients they compromise our nutrition. During the refining process important nutrients like vitamins and enzymes are removed and we need to get them elsewhere. As a result every day more people are diagnosed with serious diseases and many chronic illnesses are reaching epidemic proportions. A way out of this has been given by Hippocrates (500 B.C), the father of medicine who stated: "Let your food be your medicine and your medicine be your food".

The role of medicinal mushrooms as "functional foods" was known for thousand of years especially in the countries of the East but only recently was recognized by modern science [1-3]. The β-glucans in medicinal mushrooms were shown to boost the immune system to fight infection while down regulate the part that results in chronic inflammation [4].

Dietary intake of *Agaricus bisporus* (white button mushroom) accelerates salivary immunoglobulin A (SIgA) secretion in healthy volunteers [5]. Secretory SIgA acts as the first line of adaptive humoral immune defense at mucosal surfaces. There was a 50% increase in the secretion of SIgA in healthy volunteers when they consumed button mushrooms as part of their regular diet.

Mushrooms appear to have anti-inflammatory effect on human arterial lining cells *in vitro*, which may help to inhibit the progression of atherosclerotic heart disease [6,7]. Antioxidant properties of phenolic compounds are also found in edible mushrooms [8]. This is probably due to bioactive compound Pyrogallol, a phenol also found in the medicinal plant *Embolia officianalis* (goos berries). Another antioxidant compound *ergothioneine* an amino acid is found in mushrooms at a concentration 40 times higher than in beans the closest competitor.

The daily consumption of mushrooms may be sufficient to suppress breast tumor growth *in vitro* and *in vivo* by inhibiting the enzyme *aromatase* which promotes estrogen biosynthesis. Daily serving of mushrooms in Asian women averaged just 15 a month appeared to lower their risk of developing breast cancer by as much as 64% compared to those women who did not regularly eat any mushrooms [9]. Therefore mushroom nutrition may be useful for the prevention of breast cancer in post menopausal women [10, 11].

The immonostimulatory action of mushrooms is attributed to the presence of various bioactive compounds with β-glucans being the most important ones.

The mode of action of medicinal mushrooms is accomplished by non specific immunostimulation due to the presence of a number of specific receptor sites of the immune cells to mushroom β-glucans [12]. The β-glucans are not degraded by the enzymes of the peptic system and pass intact into the small intestine where they are captured by the macrophages *via* the Dectin-1 receptor with or without the receptor TLR-2/6. Then they are fragmented into smaller molecules and the β-glucan fragments are carried to the bone marrow and endothelial reticular system. These small fragments are then taken up by various reactor cells *via* the following receptors:

a) Dectin-1 (monocytes, neutrophils and Dendritic cells)

*Address correspondence to this author at the Institute of Technology of Agricultural Products, NAGREF – ELGO – DEMETER, 1. S.Venizelou, Lycovrissi, 14123, Athens, Greece; Tel: +30-210 2845940; Fax: +30-210 2840740; E-mail: cisrailides@yahoo.gr

ISSN: 1927-3037/14

b) CR 3 (neutrophils and NK cells)

c) SIGNR 1 (macrophage and Dendritic cells)

d) La Cer (neutrophils)

e) Scavenger (neutrophils)

The result is the induction of both humoral and cell-mediated immunity [12].

The structural complexity of the molecules of β-glucans follows the biological complexity of the sources from which they originate. Hence mushrooms have higher complexity of β-glucan molecules than yeasts and bacteria [13]. This creates a requirement for further research regarding the action of β-glucans coming from different sources. Many basidiomycetes are grown and utilize agro industrial wastes as substrates which enhance the production of β-glucans by the induction of certain enzymes such as β-glucan synthase as in the case of olive mill waste waters [14]. Although all edible mushrooms comprise a very healthy and nutritious food, the medicinal mushrooms are considered a better source for β-glucans and are a class higher than the majority of culinary species.

Today mushroom β-glucans are found in the market more in the form of capsules or tablets as food supplements and to a lesser extent as ingredients in the food products. In the latter case it is most likely to find glucans from yeasts or plants. In the food industry β-glucans from *Pleurotus ostreatus* and *Lentinula edodes* have demonstrated satisfactory results when added to yogurt [15] and in the making of extruded snack products with low glycemic index [16]. Also chicken burgers were enriched with *Pleurotus sajor-caju*, fiber and β-glucans [17] as well as *Pleurotus ostreatus* was incorporated into sausages in an effort to lower their fat content [18]. Low fat yogurt was enhanced, by adding fiber-containing β-glucans to create what is known as "low-fat yogurt mix". Experiments at USDA-ARS showed that when 0.3g of pure oat β-glucan was added to 100 g of yogurt no significant change in the key yogurt qualities was observed and no noticeably affect to the consumers as far as taste and texture is concerned [19].

There are approximately more than 3,000 species of mushrooms which can be considered mainly as edible. Of these mushrooms only 200 species have been developed experimentally, 100 grown on a small scale, 60 of them with commercially potential use and only 10 are produced in an industrial scale. Table **1** shows the most commonly grown mushrooms with their potential medical applications [20].

In the feed industry there are many commercial products available based on β-glucans from

Table 1: Some of the Most Commercial Mushrooms with Potential Activities and Applications

Mushroom Latin name	Common name	Active compound	Potential Activities / Application	Ref.
Agaricus bisporus	White button mushroom	(1→3), (1→6) linked β-D-Glucan	Immunostimulatory/ Pharmaceutical use	[5]
Lentinula edodes	Shitake	Lentinan, glucan, mannoglucan, proteoglycan	Immunostimulatory/ Pharmaceutical use; Dietary Supplements; Food additives and Aquaculture Husbandry- as feed additives	[15, 21]
Pleurotus ostreatus	Oyster mushroom	Pleuran, heterogalactan, proteoglycan	Immunostimulatory/ Pharmaceutical use; Dietary Supplements; Food additives and Aquaculture Husbandry- as feed additives	[15, 16, 18, 20, 22, 23]
Pleurotus sajor - caju	Oyster mushroom	(1→3), (1→6) linked β-D-Glucan	Immunostimulatory –Diabetes / Pharmaceutical use; Dietary Supplements	[32, 17]
Volvariella volvacea	straw mushroom	(1→3) β-D-Glucan	Immunostimulatory- Antitumor / Pharmaceutical use	[33]
Grifola frondosa	Maitake	Grifolan [(1→3), (1→6) linked β-D-Glucan] proteoglycan, heteroglycan, galactomannan	Immunostimulatory / Pharmaceutical use	[34]
Ganoderma lucidum	Reishi	Ganoderan, Heteroglycan, mannoglucan, glycopeptide	Immunostimulatory / Pharmaceutical use	[34]

mushrooms species. These species are cultivated on a commercial scale and have a rapid growth and are able to produce in a short time high biomass. As a result they are able to provide a steady source of beta-glucan to feed the needs of an enlarged market. These are used as feed supplements aiming at the stimulation of the animal's immune system and hence avoiding the overuse of antibiotics in the feed industry. Such immunostimulation was noticed with β-glucans from *Pleurotus ostreatus* fed to chicken [21]. Also β-glucan from *Lentinula edodes* has been applied to fish feed for immuno-modulation in rainbow trout (*Oncorhynchus mykiss*) [22], from *Pleurotus florida* in Major Carp (*Catla catta*) [23] and from *Pleurotus ostreatus* in common carp (*Cyprinus caprio L.*) [24].

The World Health Organization in an attempt to halt the spread in the human population and to the global livestock with resistant pathogens produced from the excessive use of antibiotics created from the antibiotic resistance genes in the gene pool of the natural microbial flora, proposed to ban the use of these antibiotics for the prevention of diseases in animal farms or antibiotics used as accelerators for weight gain in the animal husbandry. [25]

Especially the ban of the antibiotics in livestock for non-therapeutic purposes (antibiotics used as accelerators for weight gain in the animal husbandry), is gaining ground and is applied in many countries. For example in the European Union with the regulation IP/05/1687), 22 December 2005, the use of four antibiotics was banned as growth promoters in animal feed applying it in all member countries.

The β-glucans from the mushrooms commercially produced have the potential to replace the antibiotics used in the livestock for non-therapeutic purposes due to their immunostimulatory properties without having adverse effect on the size and the quality of the animal production [26-31].

CONCLUSION

Mushroom immunonutrition is advocated by many health care professionals and has been proven to have many health benefits in epidemiological as well as *in vitro* and *in vivo* clinical studies. Among the many bioactive compounds present in mushrooms, prominent position has the β-glucans.

B-glucans from prokaryotic or eukaryotic organisms especially medicinal mushrooms can be incorporated into foods and feeds, creating novel "functional foods" with many health promoting benefits reducing the risk of chronic diseases beyond the nutritive value of both.

ACKNOWLEDGEMENT

The authors are thankful to Ms Maria Delatola for her help in typing the manuscript**.**

REFERENCES

[1] Chang ST, Miles PG. Mushrooms Cultivation, Nutritional Value, Medicinal Effect and Environmental Impact, Second Edition 2004. CRC Press Baca Raton London, New York, Washington DC. http://dx.doi.org/10.1201/9780203492086

[2] Chang ST, Wasser SP. The Role of Culinary-Medicinal Mushrooms on Human Welfare with a Pyramid Model for Human Health. Int J Med Mushrooms 2012; 14: 95-134. http://dx.doi.org/10.1615/IntJMedMushr.v14.i2.10

[3] Reis FS, Barros L, Martins A, Ferreira ICFR. Chemical composition and nutritional value of the most widely appreciated cultivated mushrooms: an inter-species comparative study. Food Chem Toxicol 2012; 2012; 50: 191-97. http://dx.doi.org/10.1016/j.fct.2011.10.056

[4] Rop O, Mlcek J, Jurikova T. Beta – glucans in higher fungi and their health effects. Nut Rev 2009; 67: 624-31. http://dx.doi.org/10.1111/j.1753-4887.2009.00230.x

[5] Jeong SC, Koyyalamudi SR, Pang G. Dietary intake of Agaricus bisporus white button mushroom accelerates salivary immunoglobulin A secretion in healthy volunteers, Nutrition 2012; 28: 527-31. http://dx.doi.org/10.1016/j.nut.2011.08.005

[6] Moro C, Palacios I, Lozano M, Arrigo MD, Guillamón E, Villares A, Martínez JA, Lafuente GA. Anti-inflammatory activity of methanolic extracts from edible mushrooms in LPS activated RAW 264.7 macrophages. Food Chem 2012; 130: 350-5. http://dx.doi.org/10.1016/j.foodchem.2011.07.049

[7] Hansson GK. Inflammation, atherosclerosis, and coronary artery disease. N Engl J Med 2005; 352(16): 1685-95. http://dx.doi.org/10.1056/NEJMra043430

[8] Palacios I, Lozano M, Moro C, D'Arrigo M, Rostagno MA, Martínez JA, Lafuente AG, Guillamón E, Villares A. Antioxidant properties of phenolic compounds occurring in edible mushrooms. Food Chem 2011; 128: 674-8. http://dx.doi.org/10.1016/j.foodchem.2011.03.085

[9] Zhang M, Huang J, Xie X, Holman CD. Dietary intake of mushrooms and green tea combine to reduce the risk of breast cancer in Chinese women. Int J Cancer 2009; 124: 1404-8. http://dx.doi.org/10.1002/ijc.24047

[10] Grube BJ, Eng ET, Kao YC, Kwon A, Chen S. White Button Mushroom Phytochemicals Inhibit Aromatase Activity and Breast Cancer Cell Proliferation. J Nutr 2001; 131: 3288-93.

[11] Chen S, Oh SR, Phung S, Hur G, Ye JJ, Kwok SL, Shrode GE, Belury M, Adams LS, Dudley W. Anti-Aromatase Activity of Phytochemicals in White Button Mushrooms (*Agaricus bisporus*). Cancer Res 2006; 66: 12026. http://dx.doi.org/10.1158/0008-5472.CAN-06-2206

[12] Godfrey CFC, Chan WK, Sze DMY. The effects of beta-glucan on human immune and cancer cells. J Hematol Oncol 2009; 2: 25. http://dx.doi.org/10.1186/1756-8722-2-25

[13] Otakar R, Mlcek J, Jurikova T. Beta-glucans in higher fungi and their health effects 2009 Nut Rev 67: 624-31. doi:10.1111/j.1753-4887.2009.00230.x

[14] Reverberi M, Di Mario F, Tomati U. β-Glucan synthase induction in mushrooms grown on olive mill wastewaters. Appl Microbiol Biotechnol 2004; 66: 217-25. http://dx.doi.org/10.1007/s00253-004-1662-y

[15] Hozova B, Kuniak L, Kelemova B. Application of β-glucans isolated from mushrooms Pleurotus ostreatus (pleuran) and Lentinula edodes (lentinan) for increasing the bioactivity of yoghurts. Czech J Food Sci 2004; 22: 204-14.

[16] Brennan MA, Derbyshire E, Tiwari BK, Brennan C. Integration of β-Glucan Fibre Rich Fractions from Barley and Mushrooms to Form Healthy Extruded Snacks. Plant Food Human Nutr 2013; 68(1): 78-82. http://dx.doi.org/10.1007/s11130-012-0330-0

[17] Wan Rosli WI, Solihah MA, Aishah M, Fakurudin NA, Mohsin SSJ. Colour, texture properties, cooking characteristics and fibre content of chicken patty added with oyster mushroom (Pleurotus sajor-caju). Int Food Res J 2011; 18: 621-7.

[18] Chockchaisawasdee S, Namjaidee S, Pochana S, Stathopoulos CE. Development of fermented oyster-mushroom sausage. Asian J Food Agro-Ind 2010; 3: 35-43.

[19] Singh M, Kim S, Sean XL. Effect of Purified Oat β-Glucan on Fermentation of Set-Style Yogurt Mix. J Food Sci 2012; 77: E195-E201. http://dx.doi.org/10.1111/j.1750-3841.2012.02828.x

[20] Chang ST, Philip GM. Mushrooms Cultivation, Nutritional Value, Medicinal Effect, and Environmental Impact, Second Edition 2004. http://dx.doi.org/10.1201/9780203492086

[21] Muthusamy G, Joardar SN, Samanta I, Isore DP, Roy B, Maiti KT. B-Glucan from edible mushroom (Pleurotus florida) enhances mucosal immunity in poultry. Adv Anim Vet Sci 2013; 1: 116-9.

[22] Djordievic B, Skugor S, Jorgensen SM, Overland M, Myland LT, Krasnov A. Modulation of splenic immune response to bacterial lipopolysaccride in rainbow trout (*Oncorhynhus mykiss*) fed lentininan, a b-glucan from mushroom Lentinula edodes. Fish Shellfish Immunol 2009; 26: 201-9. http://dx.doi.org/10.1016/j.fsi.2008.10.012

[23] Dibyendu K, Siddhatha NJ, Bimal CM, Tapas KM. Effects of a Glucan from the Edible Mushroom (Pleurotus florida) as an Immunostimulant in Farmed Indian Major Carp (Catla catla). Israeli J Aquacult-Bamidgeh 2008; 60(1): 37-45.

[24] Dobsíková R, Blahová J, Mikulíková I, Modrá H, Prásková E, Svobodová Z, Skoric M, Jarkovský, Siwicki AK. The effect of oyster mushroom b-1.3/1.6 –D-glucan and oxytetracycline antibiotic on biometrical, haematological, biochemical, and immunological indices, and histopathological changes in common carp (*Cyprinus carpio* L.) Fish Shellfish Immunol 2013; 35: 1813-23. http://dx.doi.org/10.1016/j.fsi.2013.09.006

[25] Bonnie MM, Levy SB. Food Animals and Antimicrobials: Impacts on Human Health. Clin Microbiol Rev 2011, 24: 718-33. http://dx.doi.org/10.1128/CMR.00002-11

[26] Cueno RP, Morillo TB, Carter SD, Lachmann MS, Park JS, Schneider JD. Evaluation of Beta-Glucan and Antibiotics on Growth Performance and Carcass Traits of Weanling and Finishing Pigs. Copyright 2004 Oklahoma Agriculture Experiment Station.

[27] Hahn T-W, Lohakare JD, Lee SL, Moon WK, Chae BJ. Effects of supplementation of b-glucans on growth performance, nutrient digestibility. J Anim Sci 2006; 84: 1422-8.

[28] Khalkhane AS, Abbasi K, Zadeh FS, Arian AH. Effect of Dietary Beta-Glucan Supplementation on Humoral and Cellular Immunologic Factors in Lambs. Global Veterinaria 2013; 11: 38-43. DOI: 10.5829/idosi.gv.2013.11.1.73188

[29] Li J, Li DF, Xing JJ, Cheng ZB, Lai CH. Effects of β-glucan extracted from Saccharomyces cerevisiae on growth performance, and immunological and somatotropic responses of pigs challenged with *Escherichia coli* lipopolysaccharide. J Anim Sci 2006; 84: 2374-81. http://dx.doi.org/10.2527/jas.2004-541

[30] Zhang B, Guo Y, Wang Z. The Modulating Effect of β-1, 3/1, glucan Supplementation in the Diet on Performance and Immunological Responses of Broiler Chickens. Asian-Aust J Anim Sci 2008; 21: 237-44.

[31] Nocek JE, Holt MG, Oppy J. Effects of supplementation with yeast culture and enzymatically hydrolyzed yeast on performance of early lactation dairy cattle. J Dairy Sci 2011; 94: 4046-56. http://dx.doi.org/10.3168/jds.2011-4277

[32] Kanagasabapathy G, Kuppusamy UR, Malek SNA, Abdulla MA, Chua K-H, Sabaratnam V. Glucan-rich polysaccharides from Pleurotus sajor-caju (Fr.) Singer prevents glucose intolerance, insulin resistance and inflammation in C57BL/6J mice fed a high-fat diet. BMC Comp Altern Med 2012; 12: 261. http://dx.doi.org/10.1186/1472-6882-12-261

[33] Nishinari K, Doi E. Food Hydrocolloids: Structures, Properties, and Functions. P12, Plenum Press, New York 1993. http://dx.doi.org/10.1007/978-1-4615-2486-1

[34] El Enshasy HA, Hatti-Kaul R. Mushroom immunomodulators: unique molecules with unlimited applications. Trends Biotechnol 2013; 31: 668-677. http://dx.doi.org/10.1016/j.tibtech.2013.09.003

Received on 18-03-2014 Accepted on 31-03-2014 Published on 15-04-2014

DOI: http://dx.doi.org/10.6000/1927-3037.2014.03.01.3