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MINI REVIEW

Mushroom as a resilient crop: a paradigm shift from agri-litters to healthy and ecofriendly food production

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Abstract

Nutrient deficiency remains prevalent in low- and middle-income countries. In fact, in developed countries, the high standard of living and the fast-growing population rely on fast and processed foods to support their daily nourishment. However, constant consumption of processed foods has been linked to chronic diseases. The unhealthy results of instant foods serve as an eye-opener for the population to demand the availability of healthy food. Some people resort to plant-based food for health reasons and mushrooms are a great option since they have been utilized as food and drugs since time immemorial, and are a great substitute or even a replacement for unhealthy foods. Mushrooms have long been regarded as a high-nutritional-value food and a vital agent in the degradation of organic matter, an ideal decomposer of agricultural and forest litter. Additionally, mushrooms are obligatory saprophytic, spore-forming eukaryotic organisms belonging to the fungal group, which can be harnessed mostly in a healthy environment. Their dominance as a medicinal food gained global traction and are now cultivated worldwide. Mushrooms, in addition to vitamins, nucleic acids, and minerals, contain β-D-glucan, a prebiotic that has immunomodulatory and anti-inflammatory properties and can be used as an adjuvant in conventional chemotherapy. Furthermore, mushrooms increase food palatability, and their protein and carbohydrate qualities are ideal counterparts to muscle foods such as meat and fish. These edible macrofungi can be considered a superfood and a nutri-med crop with a wide range of biological potentials due to their significant benefits as a combination of food and medicine and because they are grown in an environmentally friendly manner.

1. Introduction

Superfoods are combinations of healthy food products with medicinal attributes and are cultivated using an environmentally friendly approach to their production. Nowadays, food consumption demands acceptable palatability, nutritive value and therapeutic value of the product. In this case, it leads to a higher demand for alternative food products with significant health benefits.

Plant and animal production, on the other hand, paved the way for reengineering its genetic potential to address the growing market demand. Aside from the challenges of delivering ideal products on time, environmental issues such as cattle production contributing to greenhouse gas emissions are also on the rise. Hence, the demand for plant-based foods as "better for you" and "better for the planet" took place (Boukid, 2021).

Unlike plants, mushrooms are fungi that are naturally grown in the wilderness with significant biological benefits. Generally, mushrooms possess three functionalities that include nutrition, taste and physiological attributes (Das *et al*., 2021). As a result, it can be considered as nutri-med crop. Aside from its sustenance, it has a savory taste known as "umami," mainly because of the presence of sodium salts of free amino acids such as glutamic and aspartic amino acids and 50 –nucleotides (Zhang *et al*., 2013).

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Approximately 2000 species of mushrooms are safe, edible, and suitable for medical application, although only 35 are currently commercially explored (Beulah *et al.,* 2013). Those widely known and commercially cultivated species are *Agaricus* spp. (champignon), *Lentinula edodes* (shiitake), *Pleurotus* spp. (oyster), *Volvariella volvacea* (straw), *Auricularia auricula* (wood ear), *Ganoderm*a (Reishi), *Grifola frondosa* (maitake), *Flammulina velutipes* (winter mushroom), and T*remell*a *fuciformis* (white jelly) (Lu *et al.,* 2020).

In general, agro-industrial waste is commonly used in the commercial production of these mushrooms as the substrate for fruiting. Mushroom production also requires minimal land area as compared to plants and livestock, while the spent substrate is an ideal soil conditioner. Hence, this paper elucidates the significance of mushrooms as a valuable superfood with an environmentally friendly production approach to provide additional insight and awareness about this nutrient-dense crop.

2. Global food challenges

Nutrient deficiency remains prevalent in low- and middle-income countries despite progress in achieving the United Nations Decade of Action on Nutrition 2016–2025 and the Sustainable Development Goal to "eliminate all forms of malnutrition" (FAO, 2020). In southeast Asia and Sub-Saharan Africa, insufficient dietary zinc and vitamin A deficiency are very common (Stevens *et al.,* 2015).

Furthermore, more than 800 million people are undernourished globally, while 1.5 billion to 2 billion have chronic micronutrient deficiency in minerals such as calcium, iodine, iron, selenium, zinc, and vitamins such as folate and vitamin A (Beal *et al.,* 2017). Nutrient deficiency is a major factor that can hamper the growth of a nation and prevent economic stability due to poor cognitive development and vulnerability of the population to infections and other diseases. As a result, this may lead to a higher cost of treatments and a longer recovery period that affects the workforce of a nation.

3. Edible fungi as a functional food

Most of the time fungi are associated with pests, although mushrooms are fungi that are saprophytic, spore-forming eukaryotic organisms. They are considered notable functional foods for human consumption that have been cultivated for hundreds of years in Asian countries like China and Japan (Zhang *et al.,* 2007).

Furthermore, due to its significant importance as a medicinal food, it was globally produced. Mushrooms are good source of protein with low fat and cholesterol content, making them both a nutritional food and a beneficial natural medicine because of their immunomodulatory effect (Pathak *et al*., 2022).

According to Wasser (2011), *Ganoderma lucidum, Lentinula edodes, Grifola frondosa, Hericium erinaceus, Trametes versicolor, Schizophyllum commune, Phellinus linteus, Inonotus obliquus* and *Pleuortus ostreatus* are among the mushroom species that have been mostly utilized in Asian countries. In the Philippines, *Pleurotus* species and *Volvariella volvacea* are widely grown. However, due to on-and-off production and mostly small mushroom growers engage in the production, proper documentation on this matter does not materialize.

Aside from protein, mushrooms also contain important nutrients the body needs, such as selenium, potassium, riboflavin, niacin, vitamin D, and fiber. Nutraceutical properties are also present and are noted for the prevention or treatment of Parkinson's, Alzheimer's, hypertension, and high-risk stroke. Mushrooms also reduce cancer cells and metastasis and are attributed to act as antibacterial, immune system enhancer, and cholesterol-lowering agent (Valverde *et al.,* 2015).

4. Mushrooms as key ingredients for healthy food

Chronic health problems such as obesity and an increase in the risk of diabetes are some of the negative effects of continuous consumption of processed and instant foods (Corpet, 2011; Young *et al*., 2013). These unhealthy food consumption results, for instance, leave people the chance to rethink and reconsider healthy food consumption instead. It also provides food manufacturers and other food service providers an opportunity to constantly search for natural bioactive ingredients that offer health benefits beyond their nutritive values without sacrificing the quality of the produce.

For example, mushrooms, known for their nutraceuticals, are ideally preferred in the formulation of low-calorie foods. Thus, the incorporation of mushrooms as the main ingredient in food production is favorably accepted by consumers since it offers a fibrous structure that mimics the texture of meat analogs while offering a unique taste and umami flavor (Das *et al.,* 2021).

Mushrooms, in addition, contain moisture (85–95%), carbohydrates (35–70%), protein (15–34.7%), minerals (6–10.9%) and nucleic acids (3–8%) (Rahi *et al.,* 2016). These protein qualities and minerals, when further enriched, are the ideal counterparts of muscle food such as meat and fish that are essential for daily living. Furthermore, mushrooms increase the palatability and important biological components of food when incorporated into different recipes. For instance, *Pleurotus* spp. when incorporated in patties and sausages was able to improve their chemical composition and functional health promoting properties, as well as its sensory attributes (Torres-Martínez *et al*., 2022)

Shiitake mushrooms, for example, control bacterial growth, provide sensory quality, and have a lower TBAR value when combined with Frankfurter (Pil-Nam *et al*., 2015); *Agaricus bisporus* dried powder inhibits lipid oxidation and results in higher TBAR values as well as lower malondialdehyde (MDA) and volatile aldehydes when combined with cooked ground beef (Alnoumani and Ataman, 2017). When dried *Pleurotus ostreatus* is mixed into salami, it lowers the fat content, inhibits lipid oxidation, and has no negative effect on the sensory properties (Özünlü and Ergezer, 2020). *Volvariella volvacea* increases essential amino acids by eightfold and improves physical properties when incorporated in Cantonese sausage. The addition *of Auricularia auricula* to brown rice results in exudates with a lower glycemic index and increases total phenolic concentration, which leads to a higher percentage of scavenging effect against free radicals in the DPPH assay (Vallée *et al.,* 2017). Moreover, *Agaricus blazei* shows higher antioxidant activity and reduced lipid oxidation of Omega-3 when added to milk enriched with Omega-3 (Table 1.).

5. Functionality of β-D-glucans

β-glucans, one of the most promising biological components of mushrooms, naturally occur as a soluble polysaccharide fiber in mushrooms cell wall. They are generally harvested through shaking or agitation conditions. As reported by Chotigavin *et al.* (2021), beta glucan production was able to increase by 1.4 fold when under a stirred tank reactor. In addition, *β*-glucans compose of non-starch polysaccharides, D-glucose monomers linked by *β*-glycosidic bonds, which make them called a “heterogenous group” (Zeković, 2005).

Mushroom *β*-glucans consist of *β*-(1→3) bonds in a backbone with short *β*-(1→6) branches. The triple helix structure determines the anticancer and immunomodulatory properties of mushroom *β*-glucans (Mirończuk-Chodakowska *et al.,* 2021). *β*-glucans in edible mushrooms reduce cholesterol and blood glucose levels and have antiviral, antibacterial, and antifungal properties. The possible mechanisms by which β-glucan works within the human body and acts as a prebiotic is most likely through its viscous nature and the production of short-chain fatty acids (Mitmesser and Combs, 2017)

Furthermore, viscosity can be the possible mechanism in the human gastrointestinal tract for the β-glucans to decrease serum cholesterol levels (Naumann *et al.,* 2006) and improve postprandial glucose metabolism (El-Khoury *et al.,* 2012). β-glucans also decrease bile acid absorption and increase bile acid excretion due to gelation that leads to a higher hepatic cholesterol synthesis because of the higher need for bile acid synthesis (Lia *et al*., 1995). Finally, *β*-glucan has an

Table 1. Antioxidant, antimicrobial and sensorial effects of the incorporation of edible mushrooms in food products.

Mushroom	Species Food Product	Antioxidant/Antimicrobial Effect	Reference
Dried *Lentinula edodes* (0.5%, 1% and 2%)	Frankfurter	Antioxidant stability during storage Lower TBARS than the control with NaNO2 Inhibition of aerobic bacteria counts Better flavor, taste, texture, and acceptability scores	Pil-Nam *et al*., 2015
Dried *Agaricus bisporus* powder 1%, 2% and 4%	Ground beef (0, 1, and 1.5% salt)	Inhibition of lipid oxidation Lower Volatile aldehydes and malondialdehyde	Alnoumani and Ataman, 2017
Dried *Pleurotus ostreatus* (1%, 2% and 3%)	Beef salami	Good antioxidant properties No negative effect on sensory properties reduced fat content inhibit lipid and protein oxidation	Özünlü, and Ergezer, 2021
Dried *Volvariella volvacea* (1%, 2%, 3% and 4%)	Cantonese sausage	Increases essential amino acid by 8-fold Improved physical properties	Wang *et al*., 2018
Dried *Auricularia auricula* (5%, 10% and 15%)	Brown rice extrudates	Lower glycemic index High antioxidant activity	Vallée *et al.*, 2017
Agaricus blazei (0.1%, 0.2% and 0.3% Hydroalcholic Extract)	Enriched Omega-3 milk	Good antioxidant activity decreased the lipid oxidation of Omega-3	Vital *et al.,* 2017

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anti-inflammatory effect, which is mediated through regulation of inflammatory cytokines such as interleukins (IL), nitric oxide (NO), tumor necrosis factor alpha (TNF α), and interferon gamma (INF)-γ (Du *et al.,* 2015). These significant physiological impact of β-D- glucan initially start from the mediation of dectin -1 (Brown *et al.,* 2003). (Table 2 and Figure 1).

6. Mushrooms for healthy food production in an environmentally friendly approach

Access to healthy food is a right and not a privilege that can be enjoyed by a few (Azétsop and Joy, 2013). Accessibility to healthy food is an important aspect of society, while proper nutrition plays a significant role in the overall growth and development of an individual. UNFAO (2002) emphasized that "food security pertains to accessibility of all people at all times to have physical, social and economic access to sufficient, safe, and nutritious food that meets their dietary needs and food preferences to achieve an active and healthy life."

Lack of accessibility to healthy food is a problem in food security that needs to be addressed, since everyone needs access to quality and nutritious food to pave the way for optimal growth, development, and healthy well-being in all stages of life. However, achieving the maximum potential of a healthy and balanced lifestyle is always a challenge in everyday living due to the limitations between the availability of healthy foods and the purchasing ability of consumers.

In the Philippines and other agricultural countries, agro-industrial waste offers cheap, abundant, and locally available materials that are ideal for mushroom

Table 2. β-glucan of commercially cultivated edible mushroom (Sari *et al.,* 2016).

Mushroom species	% dry matter	β-Glucans in g/100g dm
Agaricus bisporus (J. E. Lange) Imbach (white mushroom) cap	92.169	8.608
Agaricus bisporus (J. E. Lange) Imbach (white mushroom) stalk	92.203	12.296
*Agaricus bisporus (*J.E. Lange) Imbach (Brown button mushroom) cap	90.833	8.837
Agaricus bisporus (J. E. Lange) Imbach (brown button mushroom) stalk	92.278	10.079
Lentinula edodes (Berk.) Pegl. (shiitake) cap	93.457	19.779
Lentinula edodes (Berk.) Pegl. (shiitake) stalk	93.330	25.309
Cantharellus cibarius (Fr.) (chanterelle) cap	91.491	23.586
Cantharellus cibarius (Fr.) (chanterelle) stalk	91.224	26.930
Pleurotus ostreatus (Jaqu. ex Fr.) P. Kumm. (oyster mushroom)	94.280	24.231
Pleurotus eryngii (DC ex Fr.) Gill. (king oyster mushroom)	85.420	15.321
Pleurotus citrinopileatus (Sing.) (golden oyster mushroom)	90.020	15.542
Pleurotus pulmonarius (Fr. ex Fr.) Quél. (lung oyster mushroom)	87.880	17.466
Pleurotus djamor (Rumph. ex Fr.) Boedijn (pink oyster mushroom)	90.230	21.703

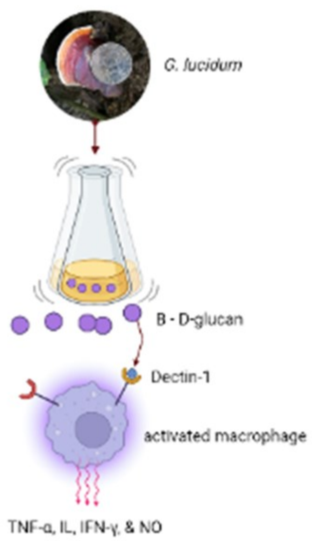

Figure 1. Macrophage activation by β-D-glucan; the figure layout was adopted from biorender.com.

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production. For instance, *Pleurotus* spp. (oyster mushrooms), *Volvariella volvacea*, *Auricularia* spp., and *Schizophyllum commune* can utilize dried banana leaves, corn stalks, rice straws, and sawdust as substrate. According to Díaz and Díaz-Godínez (2022), agroindustrial waste can be transformed into products of greater value when utilized into mushroom cultivation. Even rice hulls, the husks of the rice grains that are removed after rice milling, can serve as substrates for mushroom production. Furthermore, used mushroom substrates (spent mushroom substrates) SMS are ideal for soil improvement and proven to increase dry matter production due to its high organic matter content and availability of essential nutrients for plants (Jordan *et al*., 2008). Furthermore, spent mushroom substrate is considered as potential materials that can be used as medium in vermicomposting (Alias and Yusof, 2020). Hence, mushrooming as a crop is an environmentally friendly approach, unlike livestock, which produces more greenhouse gases, takes up more land, and pollutes arable land. Mushrooming requires little space and is made from agricultural waste.

7. Conclusion

Food, whether it comes from a restaurant or is prepared at home, is connected to all facets of life, but most importantly, to health. As a result, the food consumed will either keep people in good health or put more strain on already overburdened healthcare systems (Janssen *et al*., 2017). These scenarios may lead food consumers to demand for nutritious and readily available food in the market.

Mushrooms classified as a vegetable and an edible macrofungi, have nutritional and significant biological attributes that are beneficial to human health. Its desirable taste and nutrient content make it an ideal alternative for the high demand of the growing population for meat products. From an agricultural point of view, mushroom production is a feasible, sustainable, and eco-friendly endeavor since it converts agro-industrial waste/agri-liters into healthy food production using only a minimal amount of land area. Finally, the biotic potential of mushrooms as a health-promoting food with an environmentally friendly production approach that can be grown all year round contributes to their status as a superfood and nutrient-rich crop.

Conflict of interest

The authors declare no conflict of interest.

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