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Current trends in applications of mushrooms in food and nutraceuticals

Areeba Nadeem[a]* and Hurmat Batool[b]

a. Dr. Ikram- ul-Haq Institute of Industrial Biotechnology (IIB), Government College University, Lahore, Pakistan

Abstract: Mushrooms have been used in a variety of different food products, which have attracted great attention. These are of high value in food industry due to their unique taste, texture, and nutritive value. Moreover, these have started gaining interest in medicinal and nutraceutical diligence as well. Mushrooms are not only used by humans as food and medicines, but their biodegradability provision makes them useful for working environmental problems associated with waste disposal and soil impurity. In addition, the fast nutrition and capability to substitute mushrooms for meat are veritably useful features in sauces attracting healthy consumers as well as companies that grow other protein sources. This review article comprehensively describes the application of mushrooms in food industry, medicine, biotechnology, livestock feed and animal health and their future perspective.
Keywords: Mushrooms, medicinal, pharmaceutical, nutraceutical, packaging

1. Introduction

Mushrooms are mysterious fungi that thrive in different ecosystems and have intrigued humans for centuries. These unique organisms, belonging to the kingdom Fungi, boast a mesmerizing array of shapes, sizes, and colors (Rosmiza et al., 2016). Some are culinary darlings, celebrated with their delightful flavors, while others remain shrouded in mystery, adding an air of intrigue to the world of mycology. In their natural habitat, mushrooms play pivotal roles as decomposers, breaking down organic matter and recycling nutrients into the environment (Bulam & Üstün, 2018). Their mycelial networks interweave densely through soil, creating symbiotic partnerships with plants and trees in mycorrhizal associations, which enhance nutrient absorption and are essential to overall ecosystem health and environmental cleanliness (Moon & Lo, 2014). Mushrooms have become an integral part of the human diet and cultural behaviors. In addition to their ecological value, culinary specialists like the rich, umami flavors of Shiitake, Portobello, and Chanterelle mushrooms not only for their taste but also for the nutritional value they provide (Rajarathnam et al., 1989). These fungi are rich in essential vitamins, minerals, and antioxidants that are helpful in immune health.

In addition, mushrooms have a long history of medical usage in many cultures (Salehi, 2019). Traditional Chinese medicine, for example, points out some species for their putative immune-boosting and anti-inflammatory characteristics. Recent scientific research has focused on the medicinal potential of mushrooms, specifically substances such as beta-glucans and polysaccharides that may benefit human health and boost immunity (Manzi et al., 2004). Mushrooms are used in a variety of industries, in addition to cooking and medicine. Mycologists are utilizing their biotechnological potential for environmentally friendly solutions, such as bioremediation, to clean up contaminated habitats.

Moreover, mycelium, the vegetative part of the fungus, is becoming popular as an environmentally friendly resource for packaging and building, demonstrating mushrooms' usefulness beyond the kitchen (Rosmiza et al., 2016). As we learn further about this fungus, it becomes clear that mushrooms are more than just food on our plates; they are essential components of ecosystems, around the world's cultural traditions, and in human health. Their value goes well beyond the surface, informing us of the complex, interconnected web of life in which they play an essential part (Millikan, 2001). This review article comprehensively describes the application

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Corresponding email: areeba.nadeem1280@gmail.com (Areeba Nadeem)
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of mushrooms in the food industry, medicine, biotechnology, livestock feed, and animal health, and their future perspective.

2. Application of Mushrooms

2.1. Medical Applications

2.1.1. Immune Modulation and Nutraceuticals

Mushrooms are vital for immune system adaptation and nutritional growth. Certain mushrooms, especially shiitake and reishi, create a significant number of metabolites, including beta-glucans, which have potent immune-modulating properties (Garibay-Orijel et al., 2009). They are also helpful in the improvement of the immune system. These compounds stimulate the immune system antibodies and stimulate, enhancing its ability to protect against infection and disease. Nutritionally, mushrooms are valued for their various health benefits. Species such as maitake and lion's mane are known for improving mental health, while cordyceps and other mushrooms are recognized for their reproductive ability to help the body deal with stress. The nutritional value of mushrooms extends further into heart health, helping to create a holistic approach to good health (Millikan, 2001). As research continues in this area, mushrooms continue to be promising natural products to support the immune system and overall health with nutritional supplementation.

2.2. Cancer Research and Treatment

Mushrooms contribute to the treatment of cancer in different ways. Compounds found in mushrooms, such as polysaccharides and beta-glucans, not only inhibit tumor growth but also activate the body's immune response against cancer cells (Mortimer et al., 2012). They are known to be different bioactive compounds, which act as immunomodulators, making you more immune. Mushrooms have also been shown to reduce the side effects of conventional cancer treatments, such as chemotherapy and radiation (Camassola, 2013). These antioxidants help reduce the free radicals produced during therapy, thus reducing the oxidative stress in the body. In addition, ongoing research is exploring the possibility of chemical compounds that are derived from mushrooms to manufacture anti-cancer drugs and aid in disease treatment. The complexity of the roles of these mushrooms in immune modulation, symptom relief, and specific treatment modalities highlights the outsized potential contribution of mushrooms to cancer research and its application (Wasser, 2011).

2.3. Anti-Diabetic

Mushrooms are significant in diabetes therapy because of their unique nutritional and bioactive qualities. They are low in carbs and calories, but high in fiber, vitamins, and minerals, making them perfect for diabetics. Certain mushrooms, such as reishi and maitake, have been found to reduce blood sugar and improve insulin sensitivity, both of which are important for the treatment of diabetes. Mushroom polysaccharides and beta-glucans are also bioactive components that have anti-diabetic activities by improving insulin resistance and regulating glucose metabolism (Niksic et al., 2016). Therefore, mushrooms offer an effective and successful strategy to enhance diabetics' health, as well as prevent and treat diabetes (Manzi et al., 2004).

2.4. Anti-obesity

Mushrooms help to prevent obesity in numerous ways, because of their nutrients and bioactive components. They are low in calories and fat and high in fiber, which increases sentiments of completion and makes a difference control appetite, making them a valuable expansion to the count calories. Moreover, mushrooms contain bioactive substances such as beta-glucans and polysaccharides, which have been connected to decreasing fat and moving forward lipid digestion, making a difference to preserve a solid body. Moreover, mushrooms can be a solid and advantageous substitute for high-calorie fixings in nourishment and can help reduce calories without sacrificing taste or fulfillment. These items illustrate the capacity of mushrooms to be a vital portion of a procedure to avoid obesity, advance weight loss, and support efforts in reducing obesity that may lead to other various diseases (Camassola, 2013).

2.5. Hypercholesterolemia

Hypercholesterolemia is a condition marked by high levels of cholesterol and is a major risk factor for heart disease. Some mushrooms, including shiitake, maitake, and oyster mushrooms, have been researched for their capacity to help manage cholesterol. These mushrooms include substances such as beta-glucan, sterols, and dietary fiber, which can reduce cholesterol absorption, enhance excretion, and control lipid metabolism. For example, beta-glucan produced by mushrooms has been demonstrated to raise HDL ("good") cholesterol levels while decreasing LDL ("bad") cholesterol levels. In addition, antioxidants in mushrooms may protect against

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oxidative stress and lower the risk of vascular damage caused by excessive cholesterol. Incorporating these mushrooms into a nutritious diet may help reduce hypercholesterolemia and improve cardiovascular health (Lelley, 2005). Moreover, we should often visit the doctor for consultation about our health and immunity to prevent major risks (Rupert, 1995).

2.6. Hepatoprotective nature

The hepatoprotective properties of some mushrooms refer to their ability to protect and promote liver health. Here are some important ways in which mushrooms exhibit hepatoprotective properties (Figure 1):

Antioxidant Activity: Many mushrooms are rich in antioxidants such as polyphenols, flavonoids, and vitamin C.
Anti-inflammatory effects: Some mushrooms have anti-inflammatory properties, such as beta-glucans and triterpenoids. These medications help prevent liver damage and speed healing by reducing liver inflammation.

Detox Support: Some mushrooms, such as reishi mushroom and turkey mushroom, contain bioactive substances that support the body's detoxification process (Figure 1). They improve the liver's ability to detoxify harmful chemicals and better metabolize medications (Moon & Lo, 2014).

Liver Regeneration: Some mushrooms, such as Cordyceps sinensis, have been studied for their ability to promote liver regeneration. They may help stimulate the growth of new liver cells and improve overall liver function (Yang et al., 2002).

Immune Modulation: Mushrooms such as maitake and shiitake contain polysaccharides and other compounds that can modulate the immune system. A balanced immune system is important for liver health and the prevention of liver diseases.

Cholesterol control: Some mushrooms, especially those rich in beta-glucan, can help control cholesterol levels, thus benefiting the overall health of the heart and indirectly improving the functioning of the heart. Incorporating heart-protecting mushrooms into your diet, along with other heart-healthy practices such as not drinking too much alcohol, maintaining a healthy weight, and exercising regularly, can help you be kind and hard-working (Venturella et al., 2021) (Figure 1).

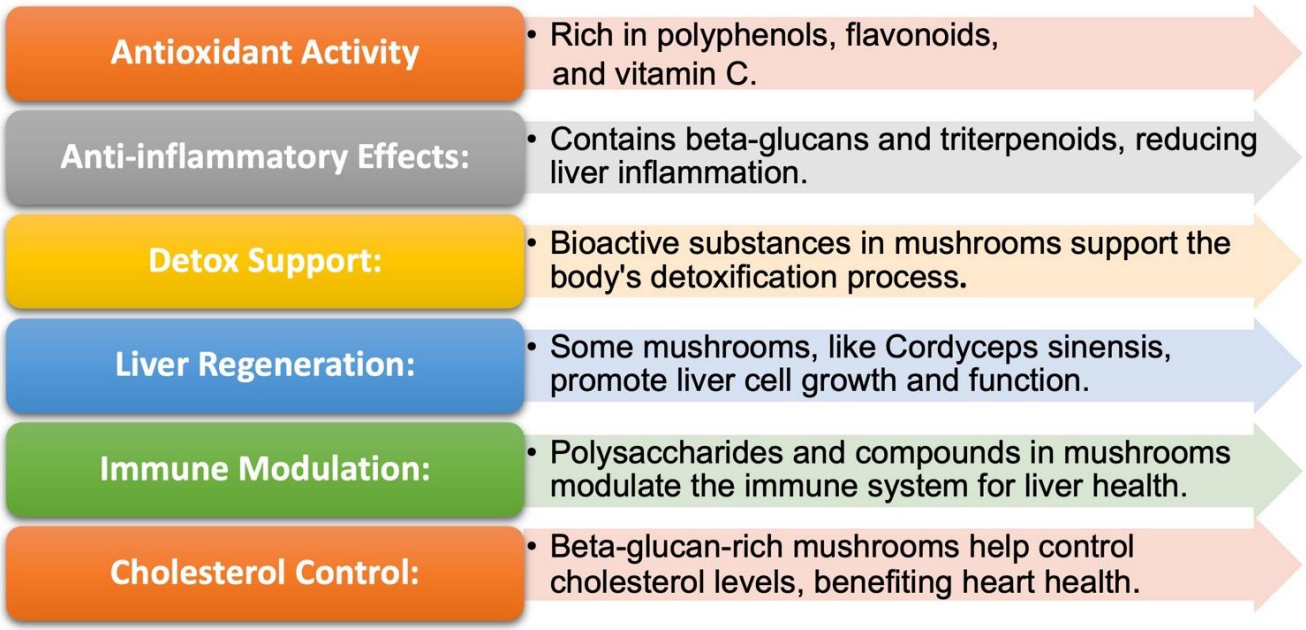

Figure 1. Different aspects of how mushrooms contribute to liver protection and overall well-being

3. Agricultural Advances

3.1. Organic Fertilizer

Mushrooms serve as a remarkable organic fertilizer in agriculture, fostering sustainable and eco-friendly cultivation practices. Mycorrhizal mushrooms form symbiotic relationships with plant roots, enhancing nutrient absorption and improving soil structure. Through this partnership, mushrooms contribute to increased plant growth, yield, and overall crop health (Mortimer et al., 2012). Their mycelial networks act as conduits for nutrient exchange, promoting a balanced and thriving ecosystem (Anthony et al., 2014). As organic fertilizers, mushrooms enrich the soil with essential nutrients, reducing the need for synthetic additives. This natural and symbiotic approach enhances agricultural productivity and aligns with environmentally conscious farming, minimizing the ecological footprint associated with traditional fertilization methods (Vunduk & Biketova, 2022).

3.2. Biological Pest Control

Mushrooms contribute to sustainable agriculture by serving as natural agents for pest control. Specific mushroom species, including Trichoderma, exhibit biopesticidal properties. These mushrooms suppress pathogens and pests in the soil, and their introduction in a cropping system will replace synthetic pesticides with nature-assisted pest-management, thus promoting a healthier and environmentally friendly approach in crop production (Yang et al., 2002). Those rooting networks of these mushrooms can inhibit the invasion of the growing root zone by pathogens. This is how agriculture can probably coexist with nature. It is food production in communion with nature. Not only food crops, but trees also benefit from their friendly mycorrhizal associates. The root and root-working networks, some of them at the rhizosphere, while the majority are underground, of the fungal component of this symbiosis assist tree plants in protecting themselves against harmful organisms, pathogens, and even pests (Millikan, 2001).

3.3. Soil Remediation

Mushrooms play an essential part in bioremediation, the method of utilizing living organisms to clean up poisons within the environment. Certain mushroom species, like clam mushrooms and white-rot organisms, have special chemicals that can break down and retain contaminants from soil and water (Anthony et al., 2014). Mushrooms use mycoremediation to successfully target and break down natural pollutants such as oil spills, pesticides, and mechanical waste (Figure 2). Mycelial systems serve as nature's filtering structure, collecting and converting hazardous compounds into nontoxic byproducts (Rupert, 1995). This is the common and cost-effective way to bioremediation, demonstrating mushrooms' potential for restoring biological systems and mitigating the environmental impact of human activities.

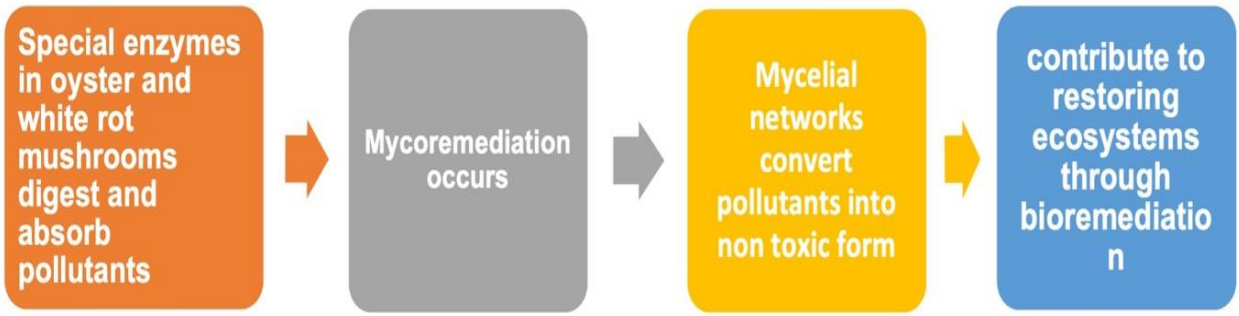

Figure 2. Role of mushrooms in bioremediation

4. Eco-friendly packaging solutions

4.1. Mycelium-based packaging

Mushrooms revolutionize sustainable packaging through mycelium-based materials. Mycelium, the root-like structure of fungi, can be cultivated to form robust and biodegradable packaging materials. As mycelium grows, it binds agricultural waste into a durable and eco-friendly alternative to traditional packaging (Camassola, 2013). This mycelium-based packaging is not only biodegradable but also customizable, providing a solution to the environmental challenges posed by conventional packaging materials. The process requires fewer resources, emits lower carbon levels, and offers a promising avenue for reducing plastic waste.

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Harnessing the versatility of mushrooms, mycelium-based packaging exemplifies a groundbreaking approach toward greener and more sustainable packaging solutions (Venturella et al., 2021).

4.2. Biodegradable Products

Some of these biodegradable products include mushroom-based packaging and disposable cutlery (Niksic et al., 2016). The advantage of mushrooms is that they disintegrate naturally on their own and do not harm the environment. In turn, mycelium can be molded into a leathery type of material (Lelley, 2005).

5. Innovations in the Textile Industry

5.1. Mushroom Leather

Mushroom leather, also known as mycelium leather, emerges as a sustainable alternative in the fashion industry. Mycelium, the root structure of mushrooms, can be cultivated to form a leather-like material without the environmental impact of traditional animal leather production (Chang & Hayes, 2013). By combining mycelium with agricultural by-products, a versatile and cruelty-free material is created (Anthony et al., 2014). This process minimizes the need for resource-intensive and polluting practices associated with conventional leather production. Mushroom leather, with its eco-friendly attributes, represents a transformative shift towards sustainable fashion, offering a stylish yet conscientious choice for those seeking ethical and environmentally responsible alternatives (Yang et al., 2002).

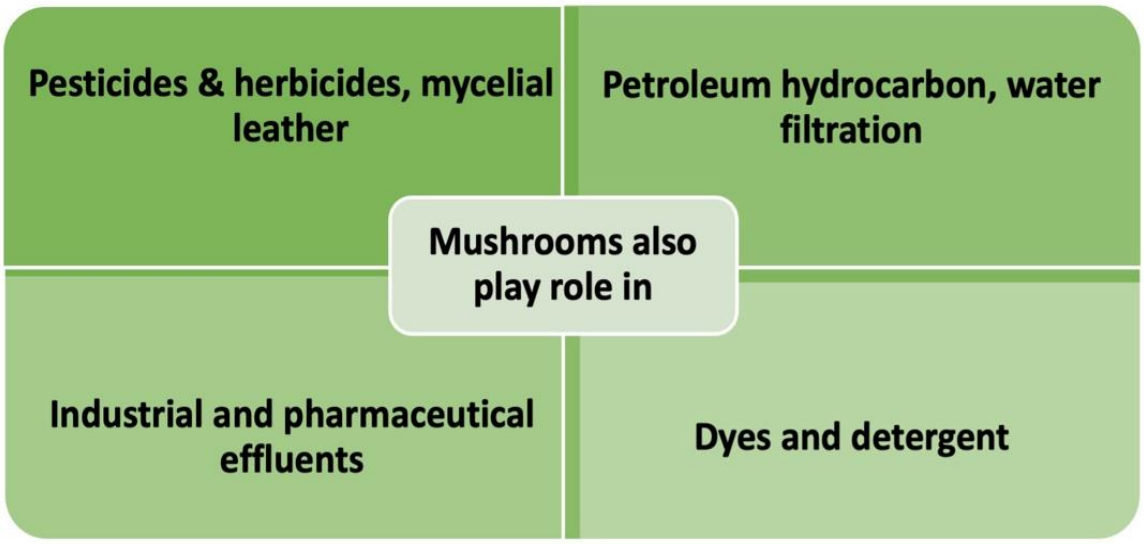

Figure 3. Role of mushrooms in different industries

5.2. Dye production

Mushrooms contribute to economic practices in color generation. Certain mushroom species contain dyes that can be extracted and utilized as common dyes for materials (Rupert, 1995). Through a process known as myco-dyeing, these colors offer a different and eco-friendly color palette. Unlike manufactured colors, mushroom-based colors are consistently biodegradable and free of toxic chemicals, reducing natural damage (Figure 3). Furthermore, myco-dyeing aligns with circular economy criteria since excess biomass from mushroom growth may be utilized for various uses (Millikan, 2001). By using the common tones determined from mushrooms, the material companies may reduce their reliance on made colors while developing sustainable and viable refinements.

5.3. Bioremediation

However, mushrooms have a great capacity to degrade as well as absorb many pollutants. Bioremediation is a quality of this property that is applied in solving environmental concerns like oil spills and industrial wastage (Lakhanpal & Rana, 2005). In general, mushrooms serve as a natural agent for removing pollutants and making them harmless.

5.4. Water filtration

Water filtration is very important, and one of the ways through which it is done is using mushrooms in a process called mycofiltration. For instance, the mycelium from certain types of mushrooms acts as a natural filter that purifies water from contaminants. It also has a very efficient way of capturing bacteria, pollutants, and heavy metals through its mycelial threads, which form a very fine net in water. The use of eco-friendly filtration is a better solution than conventional water treatment methods that mainly use chemicals in the process. Mycofiltration is an efficient way of getting water, and it's an application of mushrooms that has the ability to solve water challenges globally in an environmentally friendly way; this makes it valuable for sustainable water management, as it shows the potential of mushrooms in addressing environmental issues (Camassola, 2013).

6. Renewable Energy

6.1. Biofuel Production

Mushrooms can also provide sustainable energy through their ability to be utilized in biofuel production. A few organisms, especially those that break down wood, have proteins that are capable of converting lignocellulosic biomass to fermentable sugars. These sugars can at that point be converted into biofuels, for illustration ethanol, through a process known as fungal-mediated biomass change (Chang & Hayes, 2013). This has been a sustainable approach that uses agricultural and forestry residues instead of conventional fossil fuels, thus minimizing the adverse effects on the environment. This example of using mushrooms for biofuel production proves that fungi can not only be a source of renewable energy but also help in the recycling of waste products and promote the circular economy concept in the sphere of energy production. In the current search for better and more sustainable options for fuel, mushrooms offer viable options for eco-friendly biofuel sources (Thakur & Singh, 2013).

7. Cosmetics and Skin Care

7.1. Anti-Aging Properties

Mushrooms are a normal and effective solution when it comes to fighting the signs of aging. A few of the most prevalent sorts of mushrooms, including Tremella and Reishi, are stacked with cancer prevention agents that fight oxidative stress and free radicals, which are the most common causes of aging. These antioxidants, in conjunction with the anti-inflammatory effects of mushrooms, help to improve skin tone and minimize wrinkles (Manzi et al., 2004). Mushroom extracts used in the formulation of creams and other products used in skincare routines help in the production of collagen and hydration to make the skin healthier. Moreover, there are substances in mushrooms that help the body cleanse itself, and this is particularly beneficial for the skin, as it helps in giving a younger-looking skin. However, there is more research that needs to be done. The discovery of the anti-aging properties of mushrooms proves that mushrooms have a variety of uses when it comes to the overall health and beauty of the skin (Chang & Hayes, 2013).

7.2. Skin Whitening

Mushrooms are known to affect melanin synthesis and thus have a skin-lightening effect. Some of the mushrooms, for instance *Agaricus bisporus*, have substances that do not allow the growth of an enzyme called tyrosinase, which is useful in the formation of melanin. Hyperpigmentation or dark spots are the overproduction of melanin, which is the pigment responsible for skin color (Salehi, 2019). Mushrooms work to minimize the production of melanin by inhibiting the enzyme tyrosinase, which results in darkening of the skin; thus, they reduce hyperpigmentation and give the skin an even tone. Moreover, mushrooms have been found to contain anti-inflammatory and antioxidant components that are important in the health of the skin (Pandey et al., 2020). Mushrooms may not produce dramatic and immediate results, but they provide a natural and gentler way to achieve the desired results compared to chemicals, making them a viable option in the formulation of skincare products for people with uneven skin tone and those who want to have a brighter complexion (Niksic et al., 2016).

8. Biotechnology and Enzyme Production

8.1. Enzyme Production

Mushrooms can produce enzymes, and this biochemical aspect has shown that they have a place in many industries. Enzymes, which are catalysts that speed up chemical reactions, are contributed by mushrooms in various ways. One significant aspect is the mushroom's capability to produce and release enzymes during its growth and development. As mushrooms break down matter in their natural surroundings, they release enzymes to facilitate the decomposition process (Härkönen, 1998). These enzymes assist in breaking down

compounds into forms that the mushroom can absorb as nutrients. This natural enzymatic activity has caught the attention of researchers and industries seeking methods for enzymatic processes (Salehi, 2019). In biotechnology and industrial applications, specific mushroom species are intentionally cultivated for their properties. For example, shiitake mushrooms (Lentinula edodes) are well known for producing enzymes like laccase and peroxidase. These enzymes find applications in bioremediation by aiding in the breakdown of pollutants and contaminants in the environment (Thakur & Singh, 2013).

Additionally, the part of a mushroom is abundant in enzymes. Researchers have explored the potential of mycelium for producing enzymes used across industries such as food processing, biofuel production, and pharmaceuticals. The adaptability of mushrooms to diverse substrates, along with their machinery, makes them highly promising candidates for sustainable enzyme production (Barros et al., 2008).

8.2. Pharmaceutical bioreactors

Mushrooms contribute significantly to pharmaceutical bioreactors, serving as natural hosts to produce therapeutic compounds. Some species of mushrooms are genetically engineered to produce proteins, enzymes, or pharmaceutical compounds of interest (Chang & Hayes, 2013). Mycelia, the vegetative structures of fungi, are suitable for the biosynthesis of these bioactive compounds. Pharmaceutical bioreactors using mushroom cultures are known to have benefits such as a short growth and development cycle, affordability, and possible expansion of production (Thakur & Singh, 2013). This new concept enables the efficient, reliable, and environmentally friendly preparation of pharmaceuticals and reveals the potential of mushrooms to contribute to the biopharmaceutical industry. Mushroom-derived pharmaceutical bioreactors have shown the ability to increase in their utility and effectiveness as research and technology advancements are made, opening new possibilities for the ethical production of therapeutic compounds (Patel & Goyal, 2012).

9. Food and Beverage Industry

9.1. Flavor Enhancing

Mushrooms are a kind of spice that adds a special touch of taste to different types of food preparations. Their rich umami taste, which is described as meaty and earthy, complements other flavors in food products (Rosmiza et al., 2016). Some of the popular types are shiitake, porcini, and morel, which provide umami taste, which is excellent for both vegetarian and non-vegetarian dishes. Due to their ability to be a great complement and absorb flavors in foods, mushrooms are commonly used in various cuisines all over the world. In various cuisines, they are sautéed, grilled, or used in soups and stews, and for this reason, they occupy a special place in the kitchen as natural flavoring ingredients (Barros et al., 2008).

9.2. Beverage infusions

Mushrooms not only enhance the flavor of food but also complement beverages in a new and healthy way. Some of the most common types for this purpose include chaga, reishi, and cordyceps because of their reported health benefits. These mushrooms, when prepared as tea or used in a beverage, create an undertone of flavors that is rich and woody (Pilz & Molina, 2002). Chaga, for instance, brings a woody richness, while reishi contributes a slightly bitter undertone. Beyond flavor, these mushroom infusions are celebrated for their adaptogenic and immune-boosting properties (Cheung, 2008). As the interest in functional beverages grows, mushroom-infused drinks carve a niche, offering a delightful and nourishing alternative to traditional beverages (Miles & Chang, 2004).

10. Edible mushrooms (Psilocybin mushrooms)

Psilocybin mushrooms, famous for their mind-altering effects, are gaining recognition for their potential as more than just a recreational or spiritual substance. With compounds such as psilocybin and psilocin, these mushrooms are being heavily studied for their therapeutic properties. Psilocybin has shown promising results in treating mental health disorders like depression and anxiety, leading to breakthrough therapy designations from regulatory agencies. The pharmaceutical industry is actively exploring the development of medications based on psilocybin, and a new market of psychedelic therapy clinics is emerging, where individuals can legally and safely engage in guided psychedelic experiences. As research in this field continues to progress, new discoveries are constantly being made (Cheung, 2008). Navigating the growing landscape of psychedelic research and application involves a delicate balance between scientific advancements and ethical

considerations. To ensure responsible and beneficial usage, it is imperative to resolve regulatory issues as psychedelics become increasingly commercial (Miles & Chang, 2004).

11. Architecture and Building Materials

11.1. Mycelium Bricks

Mycelium bricks, otherwise known as mycelium composites or mycotecture, are products of mycelium biotechnology. Mycelium grows on a substrate usually made of agricultural waste, and as it grows, the mycelium forms a strong network (Barros et al., 2008). After full colonization of the substrate, the mycelium growth is then shaped and left to mature in forms such as a brick. What is obtained after this period is a strong, biodegradable material (Oyetayo, 2011). The sustainable production of mycelium bricks, therefore, transforms waste into something useful, using little or no energy, and can serve as an alternative in the construction industry. Other than being fungi and mind-blowing, mycelium bricks represent a more sustainable method of producing building materials in line with sustainable development goals and the circular economy (Yang et al., 2002).

11.2. Biodegradable packaging in the construction industry

The construction sector is looking at the use of mushroom mycelium to introduce biodegradable packaging into the industry, fundamentally changing the conversation surrounding sustainability. Image Credit: Mykor®Mushrooms are a part of most cuisines thanks to their delicious umami flavor and beneficial compounds. Whereas you may find mushrooms in soup, sandwiches, salads, and other dishes, mushroom mycelium may be more visible in your next sustainable packaging alternative. Mycelium-based packaging is one such biodegradable option that offers a solution to the environmental threats of conventional packaging, such as plastic and Styrofoam (Oyetayo, 2011). In this technique, mycelium is grown on agricultural waste or by-products, forming a stable material that can be adapted as per the use in packaging. Worthy of architecture, this mycelium-based packaging can serve as protection and insulation for delicate building materials in service and in transport as well (Mortimer et al., 2012). Once the packaging has served its purpose, it can be easily disposed of and decomposes naturally without leaving any harmful residues. This sustainable approach not only reduces the construction industry's carbon footprint but also meets the growing demand for environmentally friendly practices in modern construction projects (Lelley, 2005). The integration of biodegradable packaging made from mushroom mycelium represents a promising step towards a more sustainable and responsible future for construction sites.

12. Livestock feed and Animal Health

12.1. Livestock supplements

Mushrooms add key benefits to animal feed, making them healthier. Packed with health-boosting bits, they help fight off illness by making the immune system stronger. Adding mushrooms to feed makes digestion better and helps animals use food well, leading to better growth and more babies (Rosmiza et al., 2016). Some mushrooms even fight germs, making the gut a safer place. They also ease stress, helping animals deal with tough conditions. These boosts make sure animals are well and strong. Using mushrooms for their nutrients is a smart and effective way to boost the health of animals on farms (Lelley, 2005).

12.2. Natural remedies for pets

Mushrooms play a noteworthy role in natural remedies for pets, offering a spectrum of health benefits. Certain mushroom species, such as Reishi and Shiitake, are rich in bioactive compounds that boost the immune system, helping pets ward off illnesses. These fungi also exhibit anti-inflammatory properties, making them valuable in managing conditions like arthritis and promoting joint health (Wasser, 2011). Furthermore, mushrooms contribute to overall vitality by supporting organ function and enhancing nutrient absorption. Integrating mushroom extracts into pet supplements or incorporating them into a pet's diet can serve as a natural and holistic approach to addressing various health concerns, fostering a balanced and resilient well-being in our furry companions (Salehi, 2019).

13. Mushrooms in sustainable agriculture

13.1. Urban and vertical farming

Mushrooms prove to be invaluable in the context of urban and vertical farming due to their adaptability to controlled environments and space-efficient cultivation methods. In vertical farming systems, where space is optimized through stacked layers, mushrooms can be efficiently grown in vertical columns, making the most

of limited urban spaces. Their growth doesn't necessarily require direct sunlight, making them suitable for indoor farming setups commonly found in urban areas (Molina, 1993). Additionally, mushrooms have a quick growth cycle, enabling a continuous and high-yielding production. Their ability to thrive in these environments makes mushrooms a practical and sustainable choice, contributing to the feasibility and success of urban and vertical farming initiatives by providing a locally sourced, nutritious food option (Oyetayo, 2011).

13.2. Converting waste products into nutrients

Mushrooms play an important role in mycoremediation, which is the process of converting waste materials into useful nutrients. Specifically, a number of mushroom species have an incredible capacity to degrade organic material (Garibay-Orijel et al., 2009), turning waste materials into nutrient-rich substrates. Mushrooms are natural decomposers in rural and urban areas where managing waste is a major problem. They convert complex organic waste materials, such as agricultural wastes and some industrial byproducts, into simpler forms that plants and other organisms may use as nourishment. By converting waste materials into a useful resource for farming or environmental restoration, the mycoremediation method not only helps manage waste but also creates a sustainable cycle (Pandey et al., 2020).

14. Stress relief

14.1. Adaptogenic Dietary Supplement

Mushrooms, as an adaptogenic dietary supplement, add a unique and significant aspect to the enhancement of general health. Adaptogens are substances that help the body adjust to stress and maintain equilibrium. Two types of mushrooms that contain adaptogenic chemicals are reishi and cordyceps. These chemicals help control how the body reacts to distinctive stressors and advance strength within the body and intellect (Oyetayo, 2011). These supplements bolster resistant framework control, hormonal balance, and expanded vitality levels (Pilz & Molina, 2002). Supplements containing extracts, capsules, or powders from adaptogenic mushrooms give a total, all-natural arrangement for overseeing push, expanding vitality, and promoting long-term health and flexibility in the face of adversity.

14.2. Relaxation Teas and Tonics

Relaxing teas and tonics infused with carefully chosen mushrooms give a soothing and characteristic way to loosen up within the middle of life's boisterous pace. Mushrooms known for their unwinding characteristics, such as chamomile and Reishi, give an agreeable combination that advances relaxation and pain help (Manzi et al., 2004). These teas usually serve as more than just a refreshment; they have evolved into rites, promoting a moment of peace in an otherwise hectic day. Certain mushrooms' adaptogenic properties lead to a balanced nervous system, which helps to relieve stress and promote calm. Consolidating these mushroom-infused teas into daily routines provides a tasty and beneficial strategy to emphasize mental health (Lindequist et al., 2005).

15. Metabolic health

15.1. Glycemic control

Mushrooms contribute to glycemic control and offer a normal and nutritious choice for people looking to manage blood sugar levels. Despite their negligible impact on blood glucose levels, mushrooms provide fundamental supplements that make them a profitable addition to diets centered on glycemic control (Barros et al., 2008). One of the key variables is the mucopolysaccharide substance of mushrooms. With a constrained amount of carbohydrates and a momentous amount of fiber, mushrooms have a negligible impact on blood sugar levels when consumed. The fiber in mushrooms moderates the assimilation of glucose within the stomach-related framework, advances more steady blood sugar levels, and diminishes the probability of changes (Thakur & Singh, 2013).

Additionally, mushrooms contain bioactive substances such as beta-glucans that are being studied for their potential benefits in glycemic control. These chemicals may increase sensitivity to aggression, affect glucose digestion mechanisms, and improve blood sugar regulation. Including mushrooms in a balanced diet is especially beneficial for people with diabetes and those who need to address their blood sugar levels. As mushrooms are highly nutritious and may have a positive effect on blood sugar control, they are a pleasant and healthy way to support overall well-being.

15.2. Dietary Supplements for Weight Management

Dietary supplements play an important role in weight management, offering a simple and targeted way to support people's health efforts. Dietary supplements, when taken in conjunction with a balanced diet and regular exercise, can provide additional nutritional support and meet specific weight control needs (Manzi et al., 2004). Protein powders are often regarded as a weight control supplement. Protein is required for tissue development and repair, and including protein supplements in the diet can help preserve muscle mass, boost satiety, and improve overall metabolic health (Figure 4). Furthermore, fiber supplements like psyllium husk and glucomannan improve fullness and regulate appetite, making it simpler to restrict calorie intake (Oyetayo, 2011). Different people may respond differently to herbal supplements, so be careful and consult your doctor. In addition, taking vitamins and minerals in dietary supplements is very important to maintain a healthy state while dieting. Nutrient deficiencies can affect energy levels and metabolism, making supplementation a valuable aspect of a comprehensive weight management strategy (Thakur & Singh, 2013). Although dietary supplements are useful, they are most effective when merged into a holistic approach that includes a balanced diet, regular physical activity, and a sustainable lifestyle. It is recommended that you consult with your doctor or dietitian to ensure that dietary supplements fit your personal health goals and needs (Turtiainen et al., 2012). These supplements are described in Figure 4 below.

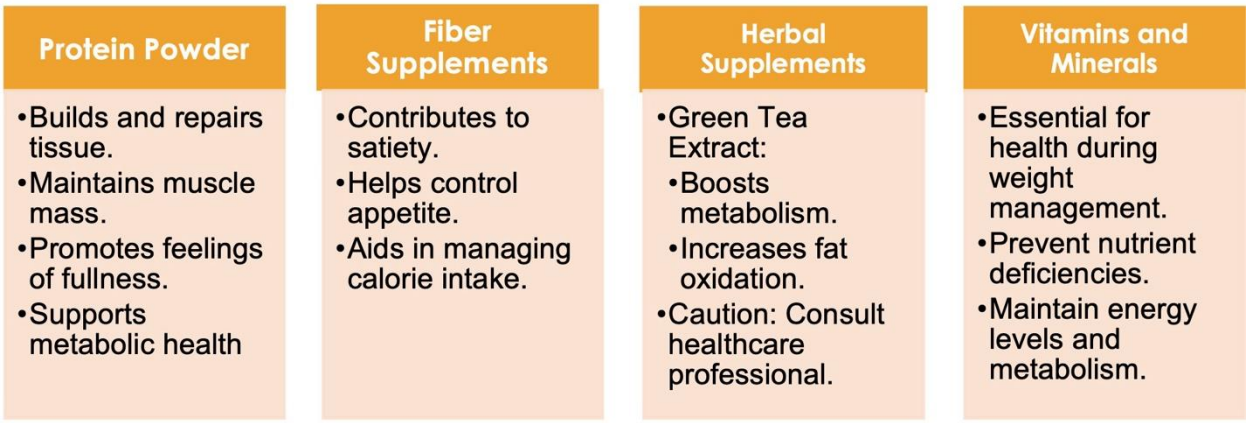

Figure 4: Dietary supplements obtained from mushrooms, including protein powder, fiber supplements, herbal supplements like green tea extract, and vitamins/minerals, help in weight management.

16. Phytochemical and nutritional quantification

16.1. Phytochemicals

Mushrooms are rich in many phytochemicals that have powerful health benefits. Some of the main phytochemicals found in mushrooms are:

Polysaccharides: Mushrooms are known for their polysaccharides, such as beta-glucan, which has an immune system-regulating effect. These medications stimulate the immune system, help the body fight infections, and may reduce the risk of some diseases (Moon & Lo, 2014).

Ergothioneine: This unique antioxidant is abundant in mushrooms, especially shiitake and oyster mushrooms. Ergothioneine has anti-inflammatory and oxidative stress properties that support health and immunity.

Phenolic Compounds: Mushrooms contain phenolic compounds such as flavonoids and phenolic acids that have antioxidant and anti-inflammatory properties. These medications may help reduce the risk of chronic diseases such as heart disease, cancer, and neurodegenerative diseases (Oyetayo, 2011).

Selenium: Some mushrooms, such as shiitake mushrooms, are good sources of selenium, a trace mineral with antioxidant properties. Selenium plays an important role in immunity, thyroid health, and DNA synthesis, and is essential for overall health.

Vitamins and Minerals: Mushrooms also contain vitamin D (when exposed to sunlight), B complex vitamins, and minerals such as potassium, phosphorus, and copper. These nutrients are essential for many body functions,

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including energy metabolism, bone health, and nervous system function. Foodstuffs. Including a variety of mushrooms in your diet can provide phytonutrients that boost immunity, reduce inflammation, and improve overall health.

16.2. Nutritional quantifications

The nutritional value of mushrooms will vary depending on the type and preparation. Here is an overview of the nutritional value of edible mushrooms per 100 grams of raw, uncooked food, as shown in Table 1:

Calories: Most mushrooms are high in calories, usually containing 15 to 30 calories per 100 grams. grams depending on the type.

Protein: Mushrooms are a good source of protein in non-animal foods. They usually contain 2 to 3 grams of protein per 100 grams.

Carbohydrates: Mushrooms are low in carbohydrates; There are approximately 2 to 4 grams of carbohydrates per 100 grams of mushrooms. It is also low in sugar.

Fiber: Mushrooms are a good source of dietary fiber, providing 1 to 2 grams of fiber per 100 grams (Thakur & Singh, 2013).

Fat: Mushrooms have a low-fat content, less than 1 gram per 100 grams. They also do not contain cholesterol.

Vitamins: Mushrooms are rich in B complex vitamins such as riboflavin (B2), niacin (B3), pantothenic acid (B5), and biotin (B7). They also contain small amounts of vitamin C and vitamin D (when exposed to sunlight).

Minerals: Mushrooms are good sources of minerals such as potassium, phosphorus, copper, selenium, and zinc. They are also low in sodium.

Other nutrients: Some mushrooms, such as shiitake mushrooms, are known for their content of ergothioneine, an antioxidant compound. Some types of mushrooms also contain small amounts of ergocalciferol (vitamin D2) and ergosterol, which convert to vitamin D2 when exposed to UV light (Table 1).

It is important to remember that cooking methods and additional ingredients can affect the nutritional value of mushrooms. For example, sautéing mushrooms in oil will increase fat content, while adding salt or fish will affect sodium. In general, mushrooms are valuable for their nutritional value and many phytochemical and health benefits (Moon & Lo, 2014).

Table 1: Nutritional content of mushrooms. (Cheung, 2008).

Nutrient	Amount per 100g
Calories	15-30 kcal
Protein	2-3 grams
Carbohydrate	2-4 grams
Fibre	1-2 grams
Fat	Less than 1 gram
VITAMINS:	
Riboflavin (B2)	Rich
Niacin (B3)	Rich
Biotin (B7)	Rich
Vitamin C	Small amount
Vitamin D	Small amount (exposed to sunlight)

MINERALS:	
Potassium	Good source
Phosphorus	Good source
Selenium	Good source
Zinc, Copper	Good source
OTHER NUTRIENTS:	
Ergothioneine	Present
Ergocalciferol (Vitamin D2)	Small amount

17. Disadvantages of Mushrooms

As we know, mushrooms have many benefits; it is important to know that there are also potential drawbacks and challenges to their various uses, and the shelf life is relatively short. This can lead to distribution and storage problems and waste if not managed effectively.

Cultural Sensitivity: Cultural sensitivity creates a major disadvantage for the commercialization of mushrooms, as diverse perceptions and beliefs surrounding these mushrooms can affect their acceptance in different communities (Chang & Hayes, 2013). Lack of recognition and respect for cultural nuances can lead to conflict, especially when marketing and distributing mushroom products that have cultural or spiritual meaning. Historical taboos and associations can create skepticism among certain groups and prevent widespread adoption of mushroom-based innovations. Companies should prioritize cultural knowledge and take into consideration the many communities in which fungi are essential components in order to address these problems (Thakur & Singh, 2013).

Possible Allergies: The potential for allergy development is one of the main drawbacks of using mushrooms for a variety of purposes. While most people think that mushrooms are safe to eat, some people are allergic to certain kinds. Allergic reactions can range from mild side effects, such as skin rashes or gastrointestinal disturbances, to severe reactions like asthma (Moon & Lo, 2014). This presents problems for advertising of mushroom-based products, since companies must assess and convey possible allergies to consumers. In case not addressed properly, it can lead to health dangers, legal issues, and harm to your brand reputation. In this manner, overcoming the allergenic potential is critical to ensure the security and availability of mushroom-derived items to the broader customers (Barros et al., 2008).

Seasonality: Seasonality could be a major challenge within the commercial utilization of mushrooms. Not at all like a few crops that can be developed year-round, numerous mushroom species have particular developing seasons. This seasonality can lead to unstable and limited supply and affect the availability of mushroom-based items within the market (Yang et al., 2002). Mushroom cultivation is seasonal, which can lead to delays and higher production costs for businesses that rely on a consistent and predictable supply chain. Additionally, customer demand for mushrooms is essentially year-round, which can lead to mismatches between demand and supply (Oyetayo, 2011). Developing a variety of crops for different growing seasons is necessary to ensure a more reliable and current marketing presence and overcome the effects of seasonality. Fungal species should potentially be combined.

Different Nutrient Contents: Different mushroom species have different nutrient content, which creates both challenges and opportunities for the commercial use of mushrooms. Although the nutritional value of mushrooms is widely recognized, the exact composition of vitamins, minerals, and other bioactive components can vary greatly between species. Companies looking to standardize nutritional information or enhance their products with specific health benefits may face challenges due to this diversity (Manzi et al., 2004). However, this allows them to offer a wider range of nutritional solutions that meet the different tastes and health needs of their customers. To fully realize the nutritional potential of mushrooms, it is important to understand and discuss with consumers the unique nutritional profiles of many species so that they can make decisions based on their own nutritional needs and preferences. This is crucial for commercial activities (Lelley, 2005).

Cultural and Culinary Preferences: Mushrooms are important ingredients in many cooking styles however different people prefer different tastes. The uniqueness of the taste or the texture may limit the acceptance of mushroom-based foods and foods containing mushrooms by some people.

Technical challenges in my core mediation: Technical challenges in my comedication, the process of using fungi to clean up environmental pollutants, are important aspects of its implementation. One of the main challenges is the specificity of fungal strains for certain pollutants, which limits the wide application of my comedication for different pollutants (Rosmiza et al., 2016). In addition, optimization of environmental conditions for fungal growth and pollutant degradation requires a detailed understanding of interactions between various factors such as temperature, pH, and substrate composition. The feasibility of micro modulation at an industrial scale remains a complex technical challenge and presents another obstacle to scale-up from in vitro experiments to large-scale real-world applications (Anthony et al., 2014).

Substrate Dependence: In mushroom production, the use of specialized substrates like agricultural wastes and wooden chips is important. Access to these substrates plays a crucial role concerning profitability and even competes with other sectors (Mortimer et al., 2012).

Potential for Misidentification: Wild mushrooms come in different varieties, often it is a difficult task to make such identification. Commercial products are usually cultivated and monitored. However, such products need to be well-labeled, especially when it comes to possible health hazards (Camassola, 2013).

Resource Intensity: Growing mushrooms on a large scale may call for huge resources like land, water, and energy, especially if mushrooms are exotic or in high demand. This is important as mushroom production grows to strike a balance between meeting the increasing demand and sustainable agriculture aimed at minimum or ideally no negative impacts on the environment (Anthony et al., 2014).

18. Conclusions

As a result, the commercial use of mushrooms is rapidly becoming an attractive area for innovation and sustainability. As we grapple with the challenges of a rapidly changing world, fungi have emerged as unsung heroes and offer countless solutions. The adaptability of these fungi is evident in a variety of commercial applications, ranging from cutting-edge medical research to eco-friendly packaging materials. The complex structures called mycelium that make up the vegetative part of mushrooms have proven to be useful partners in creating sustainable alternatives, providing a viable alternative for businesses looking to reduce their environmental impact. Additionally, the emergence of exotic, nutritious mushrooms has sparked a golden age in the culinary world. As customers seek healthier and more environmentally friendly solutions, mushrooms are becoming increasingly popular as delicious and adaptable food. With the rise of plant-based diets and their reputation as a high-protein, low-calorie option, mushrooms are becoming increasingly popular in the food industry. This has allowed for a more socially and environmentally responsible approach to nutrition. Apart from their economic importance, their commercial use effectively combines traditional knowledge with modern creativity. The therapeutic properties of mushrooms have long been valued by national cultures, but current research confirms and expands this traditional understanding. As a result of continual discoveries and technological advances, the economic potential of mushrooms will continue to develop, compelling a fascinating story of creativity, sustainability, and the close relationship between human industry and nature.

CRediT authorship contribution statement

Areeba Nadeem, Experiment and analyze data, Hurmat Batool, Data analysis, writing-original draft, editing, proofreading.

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Declaration of Competing Interest

The authors declare no conflict of interest.

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