Myconutraceuticals: A Boon to Healthcare

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ABSTRACT:
The term 'Nutraceutical' refers to a nutritionally active and medicinally potent functional food supplement. It is a therapeutic food possessing antioxidant, antimicrobial, anticancer, immunity booster, disease-preventing, and curative properties. Myconutraceuticals are nutraceuticals of fungal origin. Many fungi are famous for their therapeutic properties due to the presence of effective bioactive constituents. Owing to their rich nutritional value, high protein content, good mineral and vitamin content, low carbohydrate and fat content, and enormous medicinal potential, myconutraceuticals are becoming new therapeutic alternatives in the healthcare industry. In this research article, various myconutraceuticals have been reviewed, discussed, and summarised.

KEYWORDS: Nutraceuticals, Myconutraceuticals, Functional food, Therapeutic food.

INTRODUCTION:
The word 'nutraceutical' is conceived from two words viz., "nutrition" and "pharmaceutical" and hence it refers to the nutritionally active and medicinally potent functional food supplement. Nutraceuticals exhibit antioxidant, antimicrobial, anticancer, immunity-boosting, disease-preventing, and curative properties (Sharma, 2009, Das *et al.,* 2012). Myconutraceuticals are nutraceuticals of fungal origin. Owing to their rich nutritional profile and enormous medicinal potential, myconutraceuticals are becoming new therapeutic alternatives. To explore the role of fungi as a source of probiotics, prebiotics, dietary fibers, polyunsaturated fatty acids, polysaccharides, and antioxidants, the present review has been undertaken. This article reviews, discusses, and summarises the various types of myconutraceuticals with their nutritional and therapeutic applications in healthcare. A brief account of myconutraceuticals as a source of prebiotics, vegan proteins, polysaccharides, dietary fibers, polyunsaturated fatty acids (PUFA), antioxidants, vitamins, and minerals is presented below:

Myconutraceuticals as a Source of Prebiotics: The term 'prebiotic' refers to the food that selectively stimulates the growth of the beneficial bacterial gut flora. Recent research advancements have confirmed that mushrooms are emerging as promising alternative sources for prebiotics. Most of the mushrooms show the presence of prebiotic polysaccharides in the form of linear and branched β-glucans, with various side chain components like arabinose, mannose, fucose, galactose, xylose, glucose, and glucuronic acids. It is proved that the human stomach acid and digestive enzymes are unable to break down β-glycosidic bonds of carbohydrates generally found in edible mushrooms (Van Loo, 2006). It is reported that

Pleurotus spp., *Boletus* spp., *Lentinula edodes, Agaricus bisporus,* and *Pleurotus ostreatus* exhibit varying concentrations of β-glucans in raw and cooked form (Manzi and Pizzoferrato, 2000). Synytsya *et al.* (2008) found that extracts from *P. ostreatus* and *P. eryngii* encouraged the growth of probiotic bacteria, viz., *Bifidobacterium* spp., *Enterococcus faecium* and *Lactobacillus* spp. to varying extents. Non-digestible oligosaccharides show resistance to digestion and thereby promote the growth of colon-friendly bacteria (Gibson *et al.,* 2004; Wang, 2009). Prebiotics selectively stimulate the activity of beneficial intestinal bacteria and thereby suppress the growth of potentially harmful bacteria like *Clostridia* and *Bacteroides* (Wang, 2009; Palframan *et al.,* 2003). Studies by Duncan *et al.* (2003) and Langlands *et al.* (2004) indicated that the fermentation of inulin increased the presence of beneficial bacterial genera like *Roseburia*, *Ruminococcus*, and *Eubacterium* in the gut. *Trametes versicolor* has been reported to have β-glucans too, rendering it a prebiotic potential (Bains *et al*., 2021). However, further research is necessary to elucidate their precise mechanisms and evaluate their capacity to regulate gut flora for improved healthcare outcomes.

Myconutraceuticals as a Source of Mycoproteins - An Alternative to Animal Protein: Vegan proteins are non-meat and non-dairy-based proteins obtained from non-animal sources. These can be the probable sustainable solution to the predicted surge in protein demand for the coming years. Mycoproteins are proteins exclusively derived from fungi using fermentation technology. Proteins derived from plant sources possess off flavors due to the presence of compounds such as alcohols, ketones, furans, and aldehydes. These unsavoury flavours can be reduced by using fermentation technology. It has been demonstrated that pea proteins, on fermentation with lactic acid bacteria and Yeast species, exhibited a significant reduction in such off-flavours (El Youssef and Pascal Bonnarme, 2020).

Generally, fungi act as a good source of cholesterol-free mycoproteins (Finnigan, *et al.,* 2019 and Souza Filho, *et al.,* 2019). Mycoprotein powders obtained from mushrooms help vegetarians to remain fit and healthy by obtaining the much-needed proteins that they otherwise may not acquire from their diet. As a result of such a demand, mushrooms have been extensively researched for their rich protein content. Boda *et al*., 2012, in their survey of some edible mushrooms in Kashmir Valley explored and found out that *Agaricus bisporus*, *Morchella esculenta, Boletus edulis*, *Pleurotus sajor cajun* and *Pleurotus ostreatus* are rich in protein content.

Solid-state fermentation has made whole-cut meat production possible using mushrooms. These serve as fungi-based alternative meat products. This demand has encouraged commercial exploration of mushrooms as alternatives to meat, and a few companies have come up with their rendition of myco-meat products. MycoTechnology company has demonstrated improvement of flavor, bioavailability, and nutrition of pea and rice protein by its fermentation using shiitake mycelium. The wide availability of mushroom species is encouraging commercial food producers to produce alternatives for meat and seafood with similar tastes, textures, and flavours (Huling, 2023). *Laetiporus sulphureus*, (Chicken of the wood) tastes like chicken in cooked form. *Hericium erinaceus* (Lion's mane mushroom) exhibits close tastes to crab and seafood. *Hypomyces lactifluorum* (Lobster mushroom) tastes similar to crustacean seafood. *Pleurotus ostreatus* (Oyster mushroom) looks like oysters and tastes like bacon on cooking. *Russula xerampelina* (Shrimp mushroom) and *Entoloma abortivum* (Shrimp of the woods) taste similar to shrimp (Huling, 2023). *Pleurotus ostreatus* and *Aspergillus niger* are used as a source of commercial chitin. Also, few companies are using yeast as a commercial source of single-cell proteins. The fungal world is extensively large for the exploration of mushrooms for their mycoprotein, and this prospect holds a promising future.

Myconutraceuticals as a Source of Polysaccharides and Dietary Fibres: Many researchers have proved that synthetic foods have side effects on human health which demands the search for natural functional food that is without side effects. Mushrooms stand a good chance of being categorized as functional foods. Many of the edible mushrooms have already been explored and studied, and they are now touted as one of the best categories of functional foods. Mushrooms like *Pleurotus* sp. are one such functional foods that contain nutraceuticals like polysaccharides, dietary fibres, proteins, phenolic acid derivatives, etc. possessing anti-inflammatory, immuno-regulatory, hypoglycaemic, hepatoprotective, and antioxidant activities (Reis, *et al.,* 2017, Muszyńska, *et al.,* 2018, Gong, *et al.,* 2020, Sun, *et al.,* 2020). Beta-glucan is the natural polysaccharide found in fungal cell walls that lowers cholesterol levels, fights cancer, and reduces insulin resistance (Vetvicka, 2011). The antioxidant potential of *Lentinula edodes*, *Grifola frondosa* and *Leucopaxillus giganteus* is due to their myco-polysaccharides (Lin, *et al.,* 2019, Chen, *et al.,* 2019, Niu *et al.,* 2021). It has also been reported that *Pleurotus tuber-regium* contains valuable edible polysaccharides possessing antitumor activity (Zhang and Cheung, 2011).

Myconutraceuticals as a Source of Polyunsaturated Fatty Acids (PUFA): Polyunsaturated fatty acids become an important aspect of many functional foods, and they can be easily found in many of the fungi, as research conveys. Glamočlija *et. al*, 2015 unraveled that *A. campestris, Agaricus bitorquis*, and *A. macrosporus* are rich in functional foods due to the presence of polyunsaturated fatty acids (PUFA). The presence of PUFAs makes these fungi effective agents in improving mental and heart health. All species showed a favorable fatty acid profile for consumption. The nutritional makeup of *Lentinus sajor-caju* (syn. *Pleurotus sajor-caju*) revealed sugars and organic acids, along with lipophilic compounds such as tocopherols and PUFA (Finimundy *et al*., 2018). A lot of scope remains to inspect this aspect of the fungal world.

Myconutraceuticals as a Source of Antioxidants: Mushrooms are popular natural antioxidants possessing antiaging effects and anticancer activity (Uzma *et.al.,* 2018). *Agaricus bisporus* (White button mushroom) is edible and contains a rich source of vitamin B (Cardwell, *et.al,* 2018). Examination of *Agaricus bitorquis* demonstrated the highest DPPH radical scavenging activity (Gasecka, et.al., 2018). Triterpenoid extracted from *Sanghuangporus sanghuang* possesses antioxidant, antitumor, and anti-inflammatory activity (Dong, *et.al.,* 2023). Mature basidiocarp of *Pleurotus ostreatus* (Oyster mushroom) contains the highest levels of polyphenols and thereby possesses antioxidant activity, and DPPH scavenging activity (González-Palma, *et.al.,* 2016). *Lentinus sajor-caju* showed antioxidant activity, and anti-inflammatory, along with anti-cancer properties (Finimundy *et al*., 2018). Similarly, anti-tumor and antioxidant activities have been reported in *Cordyceps militaris* extract (Jędrejko *et al*., 2021). Tiger milk mushrooms exhibited anticancer, antimicrobial, and anti-asthmatic properties (Nallathamby, *et al.,* 2018). *Boletus* spp. is an edible antioxidants rich mushroom (Vidovi *et al.,* 2010 and Yuswan, *et al.,* 2015). Filamentous fungi like *Aspergillus unguis* are reported to produce antioxidants and antimicrobials when cultivated on potato dextrose agar (Hamed, *et al.,* 2018). As mushrooms have been extensively researched for their antioxidant potential, they have become greatly popularised as functional foods, which is also evident from the wide range of mushroom products available in the market.

Myconutraceuticals as a Source of Vitamins: Mushrooms have been also popular due to their vitamin content, and this aspect has helped them to be viewed as nutraceuticals. Vitamin B-complex in the form of thiamine, riboflavin, niacin, and biotin are abundant in mushrooms (Chang and Buswell, 1996; Breene, 1990; Mattila *et.al*, 1994; Zrodlowski, 1995; Mattila *et.al*, 2000; Mattila *et.al*, 2001). The presence of ascorbic acid (vitamin C) in mushrooms is also documented (Crisan and Sands, 1978). *Volvariella volvacea*, *Agaricus bisporus*, *Pleurotus* spp., *Lentinula edodes* possess a good amount of thiamine and niacin. *Agaricus bisporus* and *Lentinula edodes* contain higher riboflavin content than *Volvariella volvacea*. *Lentinula edodes* contain the highest vitamin C content followed by *Pleurotus sajor-caju*, *Agaricus bisporus*, and *Volvariella volvacea* (Chang, 1993). *Inonotus obliquus* has been reported to have considerable amounts of Vitamins E and K (Abu-Reidah *et al*., 2021). Fruiting bodies of *Cordyceps militaris* have shown the presence of vitamins such as Vitamin B2, B3, and C, along with Vitamin A and E (Jędrejko *et al*., 2021). Human systems show the presence of ergocalciferol and cholecalciferol (Bouillon, R., *et. al.,* 2016). Recent studies have reported that *Saccharomyces cerevisiae* can be treated with UV-B irradiation to induce the alteration of yeast sterol to ergocalciferol (Vitamin D2) to be used as a food supplement (EFSA, 2014).

Myconutraceuticals as a Source of Minerals: Mushrooms have been reported to be wonderful sources of minerals. It is estimated that the total ash content of mushrooms contains 56% to 70% of potassium, phosphorus, sodium, calcium, and magnesium (Li and Chang, 1982). Chaga mushroom (*Inonotus obliquus*) extracts were found to contain notable amounts of minerals such as Manganese (Mn), Copper (Cu), Zinc (Zn), and Selenium (Se) which give antioxidant properties to the mushroom. It also was found to contain Sodium (Na), Magnesium (Mg), Phosphorus (P), Sulphur (S), Potassium (K), and Calcium (Ca) in good quantities (Abu-Reidah *et al*., 2021). Na and Ca have been reported in many edible mushrooms, among them *Lentinus edodes* show Ca to be in large quantities. *Pleurotus sajor-caju, P. dmajor*, *P. ostreatus*, and *P. florida*, contain good amounts of copper, zinc, magnesium, and iron. *Cantharellus cibarius* and *Boletus aureus* both show considerable amounts of Mg among a lot of edible mushrooms. (Rahi and Malik, 2016). As mushrooms come out as great sources of minerals too, along with other essential components, as discussed, they become true leaders of the nutraceutical world.

DISCUSSION:

Fungi are known to acclimatize speedily to the changing ecological conditions by producing a variety of secondary metabolites. This further generates the opportunity for uncovering the unique myconutraceuticals produced by these fungi and their health benefits. The potential of fungal metabolites in improving human well-being is limitless and continually evolving (Al-Obaidi, *et al.,* 2021). According to a few reports, mushroom metabolites form good medication for neurological disorders like dementia (Yadav *et al.,* 2020). The fungus, *Cordyceps* contains cordycepin which is famous for its nutraceutical value (Ashraf, *et al.,* 2020). Specifically, *Cordyceps militaris* has shown immunostimulant, antitumor, antioxidant, anti-inflammatory, and neuroprotective activities (Jędrejko *et al*., 2021), owing to which a range of nutraceutical products are available for this fungus. *Ganoderma* nutraceuticals are used for curing and avoiding kidney diseases. It also possesses anti-inflammatory, antioxidant, and anti-tumor activities (Geng, *et al.,* 2019).

Scanning of the literature has revealed the fact that mushrooms exhibit great nutraceutical applications in human nutrition. Table no. 1 and Figure no. 1 highlight fungi with their myconutraceutical property useful in the healthcare field.

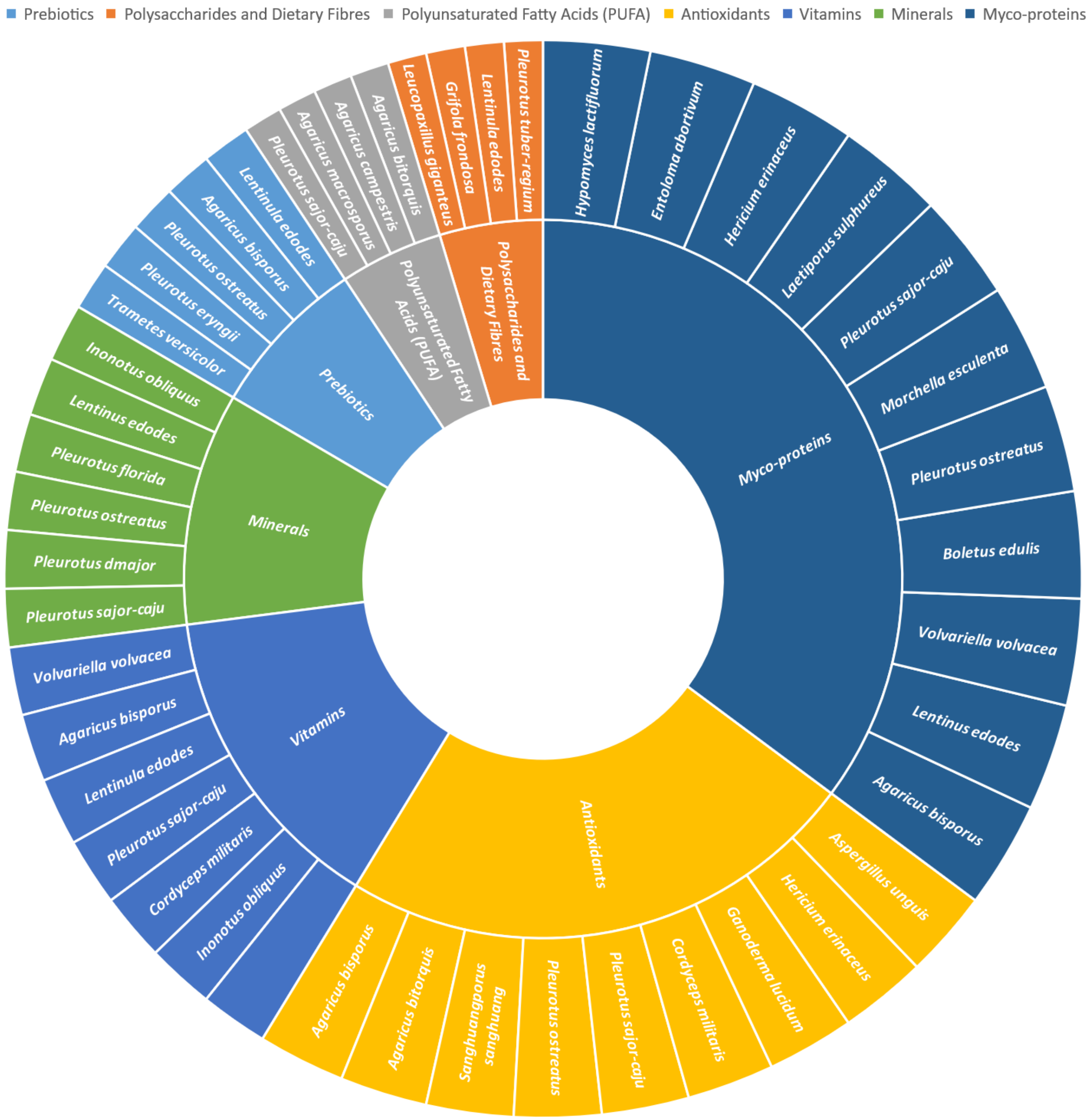
Table no. 1: Fungi with their myconutraceutical property

Sr. No.	Fungal Species	Common Name of the Fungus	Myconutraceutical Property	References
1.	*Agaricus bitorquis*	Torq, Banded Agaric, Spring Agaric, Pavement Mushroom	Highest DPPH radical scavenging activity	Gasecka, *et al*., 2018
2.	*Agaricus bisporus*	White Button Mushroom	Suppresses oxidative stress	Kimatu, *et al.,* 2017
3.	*Pleurotus ostreatus*	Oyster Mushroom	Highest levels of polyphenols; possesses antioxidant activity; DPPH radical scavenging activity	González-Palma, *et al.,* 2016
4.	*Boletus edulis*	Penny Bun, Porcino or Porcini	High concentration of phenols, flavonoids and vitamin content	Jaworska, *et al.,* 2015
5.	*Boletus luridus* (*Suillellus luridus*)	Lurid Bolete	High antioxidant ability	Zhang, *et al.,* 2018
6.	*Sanghuangporus sanghuang*	Sanghuang	Possesses antioxidant, antitumor, and anti-inflammatory activity	Dong, *et al.,* 2023
7.	*Hericium erinaceus*	Lion's Mane Mushroom	Possesses antibacterial, antitumor, and immune-modulating properties	Wu, *et al.,* 2018
8.	*Aspergillus unguis*	---	High antioxidant and antimicrobial activity	Hamed, *et al.,* 2018

9.	*Mucor circinelloides*	---	High antioxidant activity	Finnigan, *et al.*, 2019
10.	*Ganoderma lucidum*	Reishi Mushroom	Possesses anti-inflammatory and anti-tumor activities	Geng, *et al.*, 2019
11.	*Lentinula edodes*	Shiitake Mushroom	Anit-oxidant potential	Lin, *et al.*, 2019
12.	*Leucopaxillus giganteus*	Giant Funnel Mushroom	Anit-oxidant potential	Niu *et al.*, 2021
13.	*Grifola frondosa*	Maitake Mushroom	Anit-oxidant potential, anti-tumour, immunomodulatory, anti-diabetic activities, lipid metabolism regulation, hypertension control and regulation of gut flora	Chen, *et al.*, 2019; Wu, *et al.*, 2021
14.	*Pleurotus tuber-regium*	King Tuber Mushroom	Anti-tumour activity	Zhang and Cheung, 2011
15.	*Pleurotus eryngii*	King Trumpet Mushroom	Antioxidant properties, anti-cancer properties, immunostimulatory activities	Sun *et al.*, 2017
16.	*Inonotus obliquus*	Chaga Mushroom	Antioxidant, anti-inflammatory, anti-cancer, immunomodulatory, anti-allergenic, neuroprotective properties	Patel, 2015; Abu-Reidah *et al.*, 2021
17.	*Trametes versicolor*	Coriolus; Turkey Tail Mushroom	Anti-diabetic and anti-obesity, anti-inflammatory, possesses prebiotic potential	Bains *et al.*, 2021
18.	*Agaricus campestris*	Meadow Mushroom	Improves heart health, anti-anxiety properties	Glamočlija *et al.*, 2015
19.	*Agaricus macrosporus*	Macro Mushroom	Improves heart health, anti-anxiety properties	Glamočlija *et al.*, 2015
20.	*Volvariella volvacea*	Paddy Straw Mushroom	Anit-tumour, immunosuppressant, and immunomodulatory properties	Chang, 1993; Rahi and Malik, 2016
21.	*Lentinus sajor-caju*	Oyster Mushroom	Antioxidant, anti-inflammatory, anti-tumour activity	Finimundy *et al.*, 2018

22.	*Ophiocordyceps sinensis*	Caterpillar Fungus	Antioxidant, anti-inflammatory anti-tumour activity	Khan *et al*., 2010;
23.	*Cordyceps militaris*	Scarlet Caterpillar Club Fungus	Immuno-stimulating, antitumor, antioxidant, anti-inflammatory, neuroprotective activities	Jędrejko *et al*., 2021

Figure No. 1: Commonly used Fungi as Myco-nutraceuticals



Myconutraceuticals - Significance

The significance of fungi is manifold, as it encompasses several properties of nutraceuticals. They have proven to be adequate sources of carbohydrates, polyunsaturated fatty acids, antioxidants, proteins, vitamins (especially, riboflavin, niacin, folates, etc.), and minerals. They have proven to contain lesser quantities of fat and many researchers have found them to be good in dietary fibres, as well. Apart from their dietary prowess, fungi are superstars when it comes to containing good quantities of amino acids, such as aspartic acid, glutamic acid, and arginine. However, according to Chang (2008), edible mushrooms consist of lower quantities of sulfur-containing amino acids e.g., methionine and cysteine.

Fungi, especially mushrooms, form a perfect functional food for people dealing with heart diseases, high blood pressure, diabetes, and weight loss/gain. Filamentous fungi have been found to have great applications in the production of mycelium-based scaffolding materials, required for structured meat production (Huling, 2023). The use of fungal chitin / chitosan-based scaffolds is used in commercial edible food coatings and acts as a substrate for meat production (Bomkamp, *et.al.,* 2021). Fungal chitosan is a non-allergenic, safe, and approved food and nutritional additive for human consumption (Pochanavanich and Suntornsuk, 2002, Wu, *et.al.,* 2004 and Nitschke, *et.al.,* 2011).

Another important aspect of mushrooms as functional foods is that mycoprotein-based meat production eliminates the need for animal husbandry (Huling, 2023). Various advantages such as high efficiency of substrate conversion, high growth rate of biomass, easy parameter-based manipulation of microbial quantity and composition, independence from seasonal variations, etc., make the application of yeast protein attractive over animal-based sources (Nasseri, *et.al.,* 2011).

Accounting for all the important aspects of mushrooms, it is safe to say that mushrooms have become the most sought-after functional foods in the industry.

Myconutraceuticals - Challenges

Commercial production of myconutraceuticals exhibits the following challenges:

- Cultural and culinary differences in population limit the acceptance of myconutraceuticals in certain strata (Huling, 2023).
- Lack of standardization in the production of myconutraceutically rich species, growing conditions, post-harvest management, and extraction methods can cause variability in bioactive compounds resulting in inconsistent efficacy (Al-Obaidi, *et.al.,* 2001).
- Some of the myconutraceuticals are bioactive but are not effectively bioavailable to provide desired health benefits.
- Some people show allergic reactions and sensitivity to the consumption of myconutraceutical products.
- There is research lacuna on the topics like effects of myconutraceuticals and their interactions with other medications on a long-term basis.

- Managing the demand-to-supply ratio of myconutraceuticals commercially in a cost-effective manner is another challenge (Huling, 2023).

Thus, research, development, and standardization in cultivation practices, post-harvest management, extraction techniques, formulation technologies, and quality control measures are essential to prevail over these challenges and make myconutraceuticals consumer-friendly.

Myconutraceuticals - Future Prospects

Due to the availability of rich biodiverse habitats, fungi emerge as the next generations' superfood. The presence of an impressive nutritional profile and great therapeutic potential make mushrooms the perfect functional food. A literature scan reveals that comprehensive data is available on the classification, morphology, anatomy, physiology, nutritional aspects, cultivation, and postharvest technology of mushrooms. However, many fungi possessing myconutraceutical potential are untapped. Extensive research is highly needed in the areas of fungal genomics, fungal proteomics, fungal secondary metabolites, and their pharmacological and therapeutic roles (Huling, 2023).

Nutraceutical products are evolving and gaining great importance. The post-pandemic period has shown a considerable shift in market behavior and buying patterns. The Indian population has begun to believe in immunity boosters and has shown open-minded buying of nutraceutical supplements like vitamin capsules, tablets, gummies, syrups, health shakes, health vitalizers, etc. It is estimated that at the end of 2025, the Indian nutraceutical market will reach USD 18 billion (VanHorn, *et.al.,* 2023). The Indian dietary supplement market was valued at USD 3924.44 million in the year 2020 and would increase further with a growth rate of 22% per year up to 2026. (Emerging trends in nutraceutical industry, 2021)

Presently, foreign investors are greatly interested in the Indian nutraceutical market due to foreign direct investments in the food and nutraceutical supplement market. Thus, globally, India is proposed to be the main performer in the nutraceutical industry with a $100 billion market value by the end of 2030 (Shrivastava, 2023). In this context, myconutraceuticals have a bright future and hence need to be further explored. Combining the myconutraceutical research with the latest production technology would not only boost their production but would also make them available in an affordable range.

CONCLUSION:

Myconutraceuticals are the superfood that can be the solution for the increasing need to find and produce natural therapeutic agents having low carbon footprints. As the global population ages, there is rising interest in products that promote health and longevity, creating a potential market for myconutraceuticals. Research reports say that only 7% of the fungal species are screened for their bioactive compounds and hence most of them remain unexplored for their rich nutraceutical profile (Hawksworth, 2004). Future research could highlight fungi used in traditional medicinal systems as a potential source of myconutraceuticals as novel health supplements. Thus, myconutraceuticals with their unique nutritional and medicinal nature, have become a novel therapeutic boon and further provide a great opportunity for India to be the global leader in the myconutraceuticals healthcare sector.

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