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PERSPECTIVE

Fungal wonders: a perspective on various fungal benefits to mankind

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Abstract

Fungi's saprophytic way of living can be the basis of its presence during the early ages of life on earth. For many years humanity has explored fungi for technological advancement and economic growth. Hence, this review focuses on listing fungal wonders, which are products of various studies made to alleviate the societal condition of mankind. Among the benefits of fungi, its metabolites and fruiting bodies are considered as food, dietary supplements, furniture and construction materials, and, agricultural pest control. Additionally, its unique natural products are sources of novel chemicals with a higher potential for drug discovery. Its ability to decompose organic matter leads to environmental balance for nutrient cycling. Among these, fungi can restore a toxic environment by utilising heavy metals such as cadmium, copper, mercury, lead, and zinc. Thus, fungi can be mycofood, mycodrug, mycoorganic materials, mycopesticide, and mycoremediator. With these significant roles of fungi, we can deduce that these organisms can be a crucial factor in the existence of many organisms while preserving a healthy and balanced environment. Indeed, fungi are highly significant organisms with potential benefits and promising future discoveries of their significance and unique mycochemical attributes.

1. Introduction

Human needs concepts have long been central to social work practice assumptions (Jani and Reisch, 2011; Dover, 2013). This concept includes the requirement for primary needs like food and other materials essential in making work easier. However, resource depletion leads the government and industries to a crucial question: will one resource still be available at a reasonable price in a decade or a century? (Bonnin *et al.*, 2012). Hence, alternative supplies which can cover such necessities are required that are now considered in various studies. These studies involve the wonders and potential of fungi.

Fungi are unicellular and multicellular organisms like molds, yeast, and mushrooms which give critical nutrients for plant growth and provide benefits for various industries. Furthermore, Meyer *et al.* (2020), reported that fungi have the ability to transform organic materials into a rich and diverse set of useful products and provide distinct opportunities for tackling urgent challenges before all humans. These new uses of fungi all stand on the shoulders of the efforts of mycologists over generations: the scientific discipline of mycology has built a comprehensive understanding of fungal biodiversity, classification, evolution, genetics, physiology, ecology, pathogenesis and nutrition (Lange, 2014).

This review aims to elucidate the fungal wonders that are beneficial to mankind like fungal metabolites on human health aspects (Al-Fakih, 2014). Fungi contains natural product that is used as an enhancer in the hunt for unique drugs (Newman *et al.*, 2003), and substitute for a variety of foods, including beverages, baked items, and novel nutrients including animal protein sources (Derbyshire, 2020). Organic materials derive from fungi which underwent bio-based processes with sustainable alternatives that use renewable biomass to create items. We use synthetic foams, vases, furniture, lampshades, and slippers, making it an environmentally friendly alternative to plastic, rubber, wood, and leather (Nalewicki, 2017) (Figure 1). On the other hand, its

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significant role in agriculture as a decomposer and effective biosorbent, is necessary for maintaining soil organic matter by performing an essential part in the environment such as water dynamics and nutrient cycling (Yuvaraj and Murugaragavan, 2020).

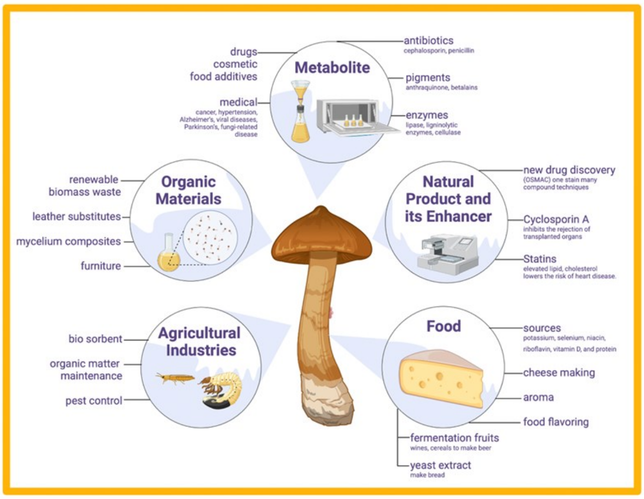
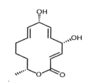
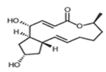
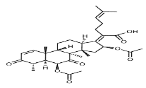
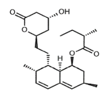
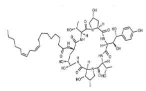
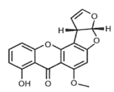
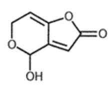
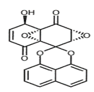
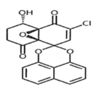
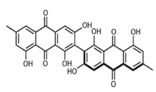
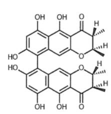


Figure 1. Graphical abstract of fungal benefits.

2. Fungal benefits to mankind

Fungi are among the ubiquitous and diverse organisms on earth. Its saprophytic way of living can be deduced from its presence during the early age of the earth. The claim of Berbee *et.al*. (2020) can support its early existence. It was also stated that Loron *et.al.* (2019) was able to find evidence of the 1-billion-year-old fungal fossils *Ourasphaira giraldae.* This is twice the age of land plants (Lutzoni *et al.*, 2018; Morris *et al.*, 2018). Fungi comprise a large kingdom that significantly impacts the living world. For instance, fungi's metabolic activity resulted in organic matter degradation (Meidute *et al.*, 2008; Brandstätter *et al.*, 2013); which primarily contributes to terrigenous C turnover by providing litter C for the microbial loop (Fabian *et al.*, 2016). Moreover, Suberkropp and Chauvet (1995) and Gadd (2006), claimed that fungi directly fulfill their demand for energy and nutrients via litter decomposition. Aside from being the primary decomposers of organic matter, fungi also serve as food and other byproducts utilized by humanity.

Table 1. Fungi metabolites, uses and chemical structure.

Fungi	Metabolites	Uses	Chemical structure	Citation
Sphaeropsidales sp. (strain F-24'707)	Mutolide	Antibacterial		Bode *et al.* (2000)
Eupenicillium brefeldi-anum (strain F-146, 140)	Brefeldin A	protein transport inhibitor		Bills *et al.* (2008)
Sarocladium oryzae	Helvolic acid	Antibacterial and antifungal		Ayyadurai *et al*. (2005)
Monascus purpureus	Lovastatin	Treatment of primary hypercholest-erolemia		Dikshit and Tallapragada, (2015)
Emericella rugulosa (F-173,113)	Echinocandin B	Fungicide		Bills *et al.* (2008)
	Sterigmatocystin	precursor to aflatoxin B1		Vieira *et al*. (2015)
Penicillium duclauxii	Patulin	stimulates Ca^{2+} entry into erythrocytes and stimulator of eryptosis		Zain *et al*. (2010), Lupescu (2013)
Berkleasmium sp. Dzf12	Diepoxin sigma	Antibacterial and antifungal, anti-cancer		Shan *et al*. (2013)
	Palmarumycin C_8	Antibacterial and antifungal, anti-cancer		
Talaromyces wort-mannii	Biemodin	Antibacterial activity against methicillin-resistant Staphylococcus aureus		Bara *et al*. (2013)
Chaetomium chiversii	Chaetochromin A	Activator of insulin receptor		Paranagama *et al*. (2007), Qiang *et al*. (2014)

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2.1 Fungal metabolites

The presence of fungi in almost every environment generates a unique chemical known as fungal metabolites that sustain its saprophytic way of living. These metabolites are unique chemicals a particular species can synthesize, divided into primary and secondary metabolites. Primary metabolites are produced for growth and development; secondary metabolites are for survival or defense mechanisms (Al-Fakih, 2014).

Generally, these metabolites are isolated and eventually considered bioactive metabolites (Daley *et al.*, 2017) (Table 1); which it is utilized as primary components or added chemical for drugs, cosmetic or food additives, production of antibiotics such as cephalosporin, penicillin, enzymes (lipase, ligninolytic enzymes, cellulase), pigments (anthraquinone, betalains), and alkaloids (ergot) are among the useful chemical that can be extracted from fungi. Additionally, fungi are also utilized in the prevention or treatment of various diseases including cancer, hypertension, Alzheimer's, viral diseases, Parkinson's, and diseases caused by various microbes as well as fungi (Kaur *et al.*, 2021).

2.2 Fungal natural product and its enhancer

Mycochemical is fungi's unique natural products that continue to lead in searching for new drug discovery. There are various applications of natural products that are still growing. Variations of these chemicals can be induced via growing media, and environmental stress of an interspecies or intraspecies relationship. For instance, the (OSMAC) one-strain many compound techniques utilize various culture media under specific conditions that aim to attain maximum compound diversity. This was initially introduced by the group of Zeek in 2000 (Bode *et al.*, 2000), since it was noted that variation in temperature, light condition, aeration and shape of vessel could greatly enhance chemical diversity in fungi. Evidently, a change from tap water to distilled water in media preparation can influence the synthesis of natural products (Paranagama *et al.*, 2007). This production technique may lead to cryptic natural products that cannot be seen in organisms grown axenically (Wiener, 1996; Tarrka *et al.*, 2009). As reported by Buckley (2008), there is a limitless array of secondary materials that fungi may synthesize which may include many antibiotics such as cyclosporin A which is a wonder drug that inhibits the rejection of transplanted organs, and statins. These are widely used in treating elevated lipid, cholesterol levels and lowering the risk of heart disease.

2.3 Fungi as food

Edible fungus is a broad name for a large group of macrofungi that contain nearly all of the nutrients' humans need and are regarded as the third food source after plant and animal-based meals (Yu *et al.*, 2020). They are high in protein, fat, cellulose, and polysaccharide, as well as minerals, amino acids, and nucleotides, which are all beneficial to one's health as they aid in human immunity, anticancer, blood lipid reduction, and other medical actions (Zhang *et al.*, 2021). For millennia, fungi have been cultivated and used to make food, food additives (such as citric acid and vinegar), feed, enzymes, medicines and, nutraceuticals (Barzee *et al.*, 2021). In addition, the edible parts of fungal biomass have long been extensively consumed as mushrooms or as a food ingredient.

Mushrooms are the oldest fungi known to man which are considered a gourmet ingredient because of their distinct flavor. There are about 2,000 varieties of mushrooms in nature, but only 25 are extensively consumed as food, and only a few are professionally grown (Geetha *et al.*, 2021). Some mushroom species are considered delicacies (e.g., truffles, boletus, morels), but cultivation attempts have been unsuccessful, with a few exceptions like *Morchella rufobrunnea* (Dupont *et al.*, 2017). However, according to Valverde *et al.* (2015), *Agaricus bisporus* is the most widely cultivated mushroom, followed by *Lentinus edodes, Pleurotus* spp. and *Flammulina velutipes*. All could be a new source of antimicrobial compounds, primarily secondary metabolites like terpenes, steroids, anthraquinones, benzoic acid derivatives, and quinolone as well as primary metabolites such as oxalic acid, peptides and proteins. Even on a dry basis, mushroom also contains protein, fat and carbohydrates (Table 2).

Table 2. Proximal composition of some edible mushrooms (dry basis).

Species	Protein	Fat	Ash	Carbohy-drates	Energy
	%	%	%	%	kcal/kg
Agaricus bisporus	14.1	2.2	9.7	74.0	325
Lentinus edodes	4.5	1.73	6.7	87.1	772
Pleurotus ostreatus	7.0	1.4	5.7	85.9	416
Pleurotus eryngii	11.0	1.5	6.2	81.4	421
Pleurotus sajor-caju	37.4	1.0	6.3	55.3	
Pleurotus giganteus	17.7	4.3	-	78.0	364

Mycoprotein is a protein-rich meal derived from filamentous fungus biomass that can be eaten as a meat substitute (Souza Filho *et al.*, 2019). These products are made with the filamentous fungus *Fusarium venenatum,* which produces mycoprotein products with a protein content of 60 to 90 percent on a dry basis when fermented in a pressure cycle fermenter in continuous aerobic mode (Barzee *et al.*, 2021).

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Coherently, fungal mycelium can also be used as a replacement for a wide range of food products, including beverages, baked foods, and innovative food products, in addition to animal protein sources (Derbyshire, 2020) (Figure 2). Stoffel *et al.* (2021) reported that *Pleurotus albidus'* mycoprotein flour as a substitute for wheat flour in producing cookies significantly altered the color, increased the hardness as well as improved the nutritional value of the cookies as measured by the contents of protein, dietary fiber, and phenolic compounds.

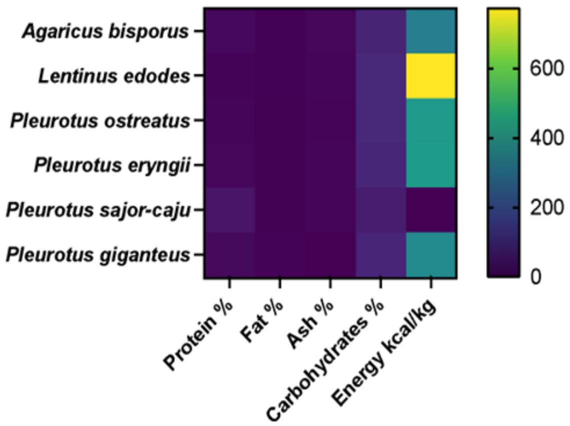

Figure 2. Heatmap of Proximal composition of some edible mushrooms (dry basis).*note: Adapted from Carneiro *et al*. (2013), Kalač (2013), Phan *et al*. (2012) and Reis *et al*. (2012)

In addition, eating edible fruiting bodies of mushrooms have been used to supplement and add flavour to foods. For instance, Kaur *et al.* (2021), claimed that edible fungi are sources of potassium, selenium, niacin, riboflavin, vitamin D, and proteins; fungi are also utilized in cheese making, aroma or food flavoring. Moreover, yeasts are used in fermentation of fruits to produce wines, cereals to make beer, and in manufacturing bread and flavoring in the form of yeast extract.

2.4 Fungi as organic materials

In industrial manufacturing strategies, the circular economy closes loops and reduces waste. A bio-based economy attempts to replace fossil-fuel-based resources and processes with sustainable alternatives that use renewable biomass to create items we need every day (Cerimi *et al*., 2019). Hence, producing fungus-based biomaterials, a contemporary trend in fungal biotechnology, can help with both of these goals.

Fungi-derived leather substitutes are a new class of socially and environmentally friendly materials that progressively match customer aesthetic and functional expectations and gain popularity as a substitute for bovine and synthetic leathers (Jones *et al*., 2021). Relatively, Haneef *et al.* (2017), claimed that fungi-derived leather substitutes often comprise biodegradable chitin (which acts as a material stabilizer) and other polysaccharides such as glucans.

Furthermore, mycelium composites are a new class of low-cost, ecologically friendly materials which can replace foams, wood, and plastics in applications such as insulation, door cores, paneling, flooring, cabinets, and other furnishings. This is because of their adjustable material qualities dependent on their composition and production technique. This was in parallel with the study of Jones *et al.* (2019) who shows its special potential as thermal and acoustic insulation foams due to their low thermal conductivity, strong acoustic absorption, and fire safety features, surpassing typical construction materials such as synthetic foams and engineered woods.

Moreover, fungi can also be turned into compostable and free of toxin furniture like chairs and tables (Jacewicz, 2015), or an array of everyday objects including vases, chairs, lampshades and slippers that makes it a sustainable alternative to materials like plastic, rubber, wood and leather (Nalewicki, 2017). Hence, fungi play an essential role in the new bio-economy by replacing products from non-renewable resources (Lange, 2014).

2.5 Fungi in agricultural industries

Even before their existence was fully acknowledged, microorganisms were exploited in agriculture and industrial operations from the dawn of civilization. Recent advances in our understanding of fungi's genetics, physiology, and biochemistry have led to the use of fungi in producing a wide range of agricultural and commercial products. In addition, the distribution of soil fungal flora is influenced by various environmental conditions (Frac *et al*., 2018).

According to Sun *et al.* (2005), fungi are very successful soil inhabitants due to their high plasticity and capacity to adopt various forms in response to adverse or unfavorable conditions. Furthermore, they can break down various forms of organic materials, degrading soil components and thereby controlling the carbon and nutrient balance because of their ability to create a wide variety of extracellular enzymes (Žifčáková *et al*., 2016). Fungi decompose dead organic matter to produce biomass, CO_2, and organic acids by accumulating toxic metals such as cadmium, copper, mercury, lead, and zinc in their fruiting bodies; many species of fungi can operate as effective biosorbents. Although these components may limit fungal growth and reproduction, these are beneficial to fungi existence (Baldrian, 2003).

Aside from this feature, bound species of *Alternaria,*

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Aspergillus, Cladosporium, Dematium, Gliocladium, Humicola, and *Metarhizium* produce a material similar to organic compounds in soil and may thus be required for soil organic matter maintenance (Yuvaraj and Murugaragavan, 2020). Nonetheless, fungi indeed perform essential roles related to water dynamics, nutrient cycling, and disease suppression. Moreover, Kaur *et al.* (2021) claimed that fungi are used as nematode control.

Finally, fungal metabolites and their by-products provide a significant role in food, drug development, growth stimulator, enzyme production, industrial materials and pest control in agricultural industries. Moreover, its saprophytic way of living plays a crucial role in enriching sub stratum richness which is indeed highly significant in the environmental balance of the globe. Exploring fungal potential is a vital endeavor to utilize its biotic potential fully.

3. Conclusion

Mycological species are rich sources of biotechnological byproduct that provide significant usage to mankind. These products are crucial or main components of food, medicine as well as bio-materials for agricultural and industrial products undertakings. Additionally, the fungi saprophytic way of living serves an essential component to sustain the balance of the ecosystem.

Conflict of interest

The authors declare no conflict of interest.

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PERSPECTIVE

