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Review article

Contribution of mushroom farming to mitigating food scarcity: Current status, challenges and potential future prospects in Pakistan

Asif Khan [a], Waheed Murad [b,**], Salahuddin [c], Sajid Ali [d], Syed Sikandar Shah [e], Sobia Ahsan Halim [f], Asaad Khalid [g], Hamdy Kashtoh [h,***], Ajmal Khan [f,i,*], Ahmed Al-Harrasi [f,****]

[a] Department of Technology, Universidade Estadual de Maringá, Umuarama, PR87501-390, Brazil
[b] Department of Botany, Abdul Wali Khan Mardan, Khyber Pakhtunkhwa, Pakistan
[c] Agricultural Research Station, Charsadda, 24520, Pakistan
[d] Department of Horticulture and Life Sciences, Yeungnam University, Gyeongsan, 38541, Republic of Korea
[e] Research Group in Advanced Oxidation Processes (AdOx), Department of Chemical Engineering, Polytechnic School of University of São Paulo, São Paulo, Brazil
[f] Natural and Medical Sciences Research Center, University of Nizwa, P.O. Box 33, Birkat Al Mauz, Nizwa, 616, Sultanate of Oman
[g] Health Research Center, Jazan University, P.O. Box: 114, Jazan, 45142, Saudi Arabia
[h] Department of Biotechnology, Yeungnam University, Gyeongsan, 38541, Gyeongbuk, Republic of Korea
[i] Department of Chemical and Biological Engineering, College of Engineering, Korea University, Seoul 02841, Republic of Korea

A R T I C L E I N F O

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A B S T R A C T

Food insecurity, pollution, and malnutrition are some critical issues tackled by the modern world in the recent era. However, edible mushrooms are nutritionally, economically, and biotechnologically valuable groups of macro fungi. Besides being an essential source of edible food, it is also exploited in pharmacological industries as a potential source of anticancer, antioxidant and immunomodulating agents. Mushrooms are not only a rich nutritional source of functional food all over the world, but also have highly significant bioactive compounds that are considered nutraceuticals, cosmeceuticals, and mycotherapeutics across the globe. However, their cultivation is very low compared to their demand. Its cultivation consents the sustainable management of agro-industrial waste and generates decent income using low inputs. Additionally, the mushroom could also be used for the recirculation of forest waste by acting as a natural decomposer that in turn creates great opportunities for the development of economically miserable developing countries, like Pakistan. Mushroom farming is one of the promising approaches to explore such unwanted agro-waste materials from the environment and ensure food security. Mushroom farming is one of the cheapest sources to overcome the deficiency caused by malnutrition. Interestingly, it supports the local economy by offering more and more livelihood opportunities

* Corresponding author.
** Corresponding author.
*** Corresponding author.
**** Corresponding author.
E-mail addresses: asif.khan359@yahoo.com (A. Khan), waheedmurad@awkum.edu.pk (W. Murad), salaaup@gmail.com (Salahuddin), sajidbioali@gmail.com (S. Ali), shah_afridi666@yahoo.com (S.S. Shah), akahmed@jazanu.edu.sa (A. Khalid), hamdy_kashtoh@ynu.ac.kr (H. Kashtoh), ajmalkhan@unizwa.edu.om (A. Khan), aharrasi@unizwa.edu.om (A. Al-Harrasi).

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and significant income sources for local and national trade. The current review article emphasizes the prompt mushroom farming industries in Pakistan that can save lives by providing cheaper nutritional food and rich income sources.

1. Introduction

Since the Neolithic time, human beings has traditionally consumed mushrooms as a source of food and medicines [1]. Even in recent times, mushrooms are considered as one of the nutritive sources of essential minerals, vitamins, and proteins [2]. In the last few decades, interest in mushrooms' pharmacological potential has rapidly increased [3]. Study of [4] mushrooms have shown several interesting novel biochemical compounds in it including benzoic acid derivatives, oxalic acid, terpenes, anthraquinones, choline, vitamins (B, C and D), quinolones. Moreover, mushrooms are enriched with essential mineral such as selenium with miraculous biological properties [5,6]. Recently, Zhang et al. [7] proved that mushrooms possess more than 100 potential medicinal properties like anti-inflammatory, anti-cancer, anti-oxidant, anti-diabetic, immunomodulation, anti-viral, anti-allergic, anti-fungal, anti-bacterial, and cardiovascular protection [8–10]. Mushrooms have been used traditionally in different cultures for the maintenance of health and rich source of food [11].

Mushrooms serves as an excellent substitute of meat, egg, fish, vegetables, fruits, and other cereals [6], due to the presence of nutrients and other essential foods contents that offers multiple health and nutritionally important supplements for human health [12]. Similarly, research also showed that cultivated and wild mushrooms contains a variety of biomolecules (proteins, carbohydrates, and lipids) with nutritional and medicinal properties [3,13]. As compared to fruits and vegetables, mushrooms are naturally gluten-free, thus making it more nutritious and delicious with no harmful effect. Interestingly, β-glucan found in mushrooms merely stimulates the immune system that contributes to the resistance against various forms of allergies and play key role in the fat metabolism in human body. Among the variety of mushrooms, split gill, oyster and shiitake are most effective in producing the β-glucan [14,15].

Mushrooms are also efficient in energy recycling via phytoremediation by using specialized fruiting structures that have unique qualities to degrade the organic substances and recycle essential nutrients into the soil [16,17]. These are some interesting capabilities of mushrooms that convert agro-waste (rich in lignocellulosic materials) into the essential proteins-rich biomass in all essential nutrients [18,19]. The conversion of such waste materials through mushrooms is of key importance in minimizing pollution in the atmosphere and acts as manure for animal feed bio-remediates and soil conditioners [11,20–23]. For example, paddy and wheat straw are generally used for commercial production of mushrooms. Paddy straw proved to be the best substrate for cultivation of oyster mushroom [12,24,25]. The fungi used for conversion of lingo-cellulosic materials into protein rich food by non-conventional method. Different types of cellulosic substrates were used for cultivation of oyster mushrooms. Next to paddy straw, wheat straw proved to be the best substrate for cultivation of *Pleurotus* species [6,25,26]. Similarly, *Sorghum* straw was also used effectively for cultivation of oyster mushrooms [6,27]. On the same way, Balasubramani et al. [6,28] successfully cultivates *Pleurotus sajor* caju on *Echinochloa frumentacea* (Poaceae) and *Eleusine coracana* (Poaceae) and grasses. Similarly, the effect of different agro-waste is used for cultivation of oyster mushroom singly or combined substrates. These agricultural wastes can be used for cultivation of mushroom, like, wheat, paddy, soybean, pigeon pea and green gram debris from different fields mushrooms and sterilized [6,24]. It is reported that ~200 billion tons of organic matter are generated annually through photosynthesis and other agro-industries which pose a serious threat to the environment. Besides, if this waste is burned/unused or rotten during monsoon season further leads to environmental deteriorations [29]. The alternate and innovative methods have evolved to effectively utilize such precious lignocellulosic materials in safer and profitable manner through solid state fermentation technology [18]. Mushroom cultivation is one of the most important source having potential to process and recycle such waste materials i.e., plants/crop residues, into valuable food stuffs for the betterment of humans, plants, and other animals [13,30].

Agriculture in Pakistan is impeded by several challenges like, acute water scarcity, poor farming practices, lack of advanced equipment, inadequate infrastructure and political instability [31,32]. To minimize such challenges, mushroom production in Pakistan is the ultimate source because of short growth cycle, low environmental impact, high nutritional value and effective land use of mushrooms make them a potential solution to food shortages [33]. Mushroom cultivation and production in Pakistan can leads to give rise an abrupt growth interest among traders and farmers is being aided by initiatives from various NGOs and government sectors [34]. On the same way, Pakistan's food security and economic stability might be greatly enhanced by mushroom agriculture with the development of value-added products, adoption of sustainable practices and advancements in production technologies [35]. Among the mushroom producing countries like the UK, Italy, Germany, France, Hungary, Japan and India; China is the leading country that exports 70 % of its mushrooms [4]. However, the demand for its cultivation is increasing with time in developing countries like Pakistan. This review aims to document the current status and possible future prospects of mushroom cultivation in Pakistan.

2. History, diversity and cultivation of mushrooms across the globe

The production of edible mushrooms was initially started in the rural mountainous areas inside the caves of France and later on it was practiced adequately through natural ways in China during 600AD [11,36]. Initially, it was found that the total global production was just 1 billion kg in 1978. However, due to the long duration, less production, and more demand in the markets, China and Japan, initially started the artificial cultivation of some edible mushroom's species [37]. During last 55 years, numerous innovative and advanced cultivation technologies were implemented that led a significant increase in the production of important mushrooms i.e., 0.3

million tons in 1961 to 18.58 million tons in 2020 (Fig. 1).

Several species of mushrooms have been studied due to its interesting applications in the daily life as a form of cheaper food, efficient medicines and the most important role in the industry and economy of countries across the globe [38]. Recently, ~14,000 known species are known of which 2000 are safe to be consumed in the human diet. However, nowadays, 30–50 mushroom species are globally considered as one of the excellent dietary source, economical, and cultivated in approximately more than 100 countries in the world [16,19]. Several varieties, including *Lentinula, Pleurotus*, *Auricularia*, *Agaricus*, *Flammulina* and *Volvariella*, are of key importance (99 % contribution) due to their quality, medicinal properties, flavor, quantitative production and consumption rate in the market [39,40]. Interestingly, the production of these species are increasing in Pakistan, Sari Lanka, India, and Bangladesh as a food, in commercial and medicinal uses, following their traditional believes (Fig. 2) [4]. Mushrooms cultivation and production is somehow an easy task; however, few strategies for substrate preparations, inoculations, incubations and production must be considered. Such conditions might depend on the mushroom's species, time, space and moisture [41]. In general, to obtain the inoculum, the mycelium is grown on the cereal grains e.g., rye, wheat, banana, or millet, called 'spawn' [15,29,38].

3. Importance of mushrooms

3.1. Source of renewable energy

The cultivation of edible mushrooms is a broad biotechnological approach for the food, health and recycling of lignocellulosic organic wastes [42]. Currently, this is one of the unique approaches that combine the production of protein-rich food with reduced environmental pollution [43]. However, after the yeast, the mushroom is the second most important commercial microbial approach with no or shallow hazardous impact on plants and animal's health (Table 1) [13].

Mushrooms, either produced naturally or artificially, have the same dietary level [47], and they play important roles in agriculture, animal husbandry, horticulture, woodland, and other important manufacturing industries [48]. For example, white roti actively oxidizes the lignin polymers by generating aromatic radicals in the form of laccases and lignin lytic peroxidases. Similarly, edible mushrooms can produce >200 kinds of different biochemical compounds through various enzymatic and non-enzymatic reactions that directly or indirectly control the production of free radicals in the body [49]. The lipids found in mushrooms are used to make biodiesel, an environmentally acceptable and sustainable fuel that lowers greenhouse gas emissions and maintains energy security [50,51]. These lipids contents are extracted from the mushroom's biomass via; a process called lipid extraction. The extracted fats are subsequently exposed to a chemical process known as transesterification, in which they react with an alcohol (often methanol and/or ethanol) in the presence of a catalyst (potassium and/or sodium hydroxide etc.) [52]. This technique yields the industrially useful byproducts glycerol and biodiesel [53].

3.2. Nutritional value of mushrooms

Edible mushrooms are a delicacy because of their excellent flavor and high nutritional values, making them nutritious and functional foods (Fig. 3) [42,54]. Mushrooms mainly constitutes water, with 5–15 % of dry matter due to variable contents of carbohydrates, proteins, fibers and minerals [55,56]. The total carbohydrate contents (50–65 % by dry weight) includes fibers and structural polysaccharides like β-glucans, chitin, hemicelluloses, and pectin, monosaccharide's derivatives and oligosaccharides, primarily

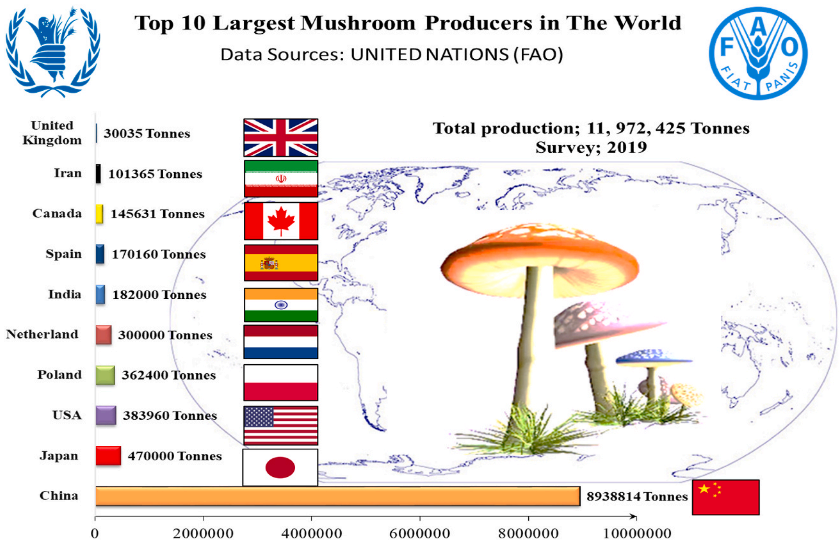

Fig. 1. Mushroom gross annual production across the globe, data was taken from FAO, 2019 (https://www.fao.org/home/en/).

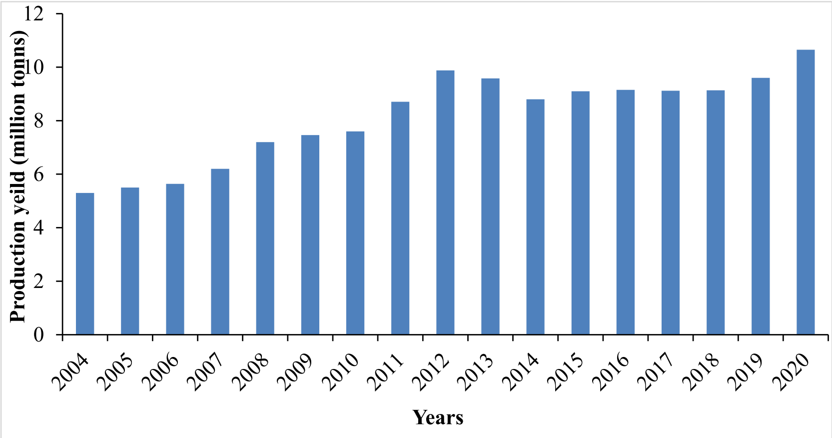

Fig. 2. Yearly production of World edible mushrooms [4].

Table 1
Comparison of different food contents including proteins, fats, carbohydrates and some essential nutrients from mushrooms and various resources were carried out [44–46].

Food resources	Proteins (g/100 g)	Fats (g/100 g)	Carbohydrates (g/100 g)	Important nutrients
Mushrooms	3.1	0.3	3.3	Vitamin D, Potassiums (2 B and B3)
Chicken breast	3.1	3.6	0	Vitamin B, Selenium and phosphorus
Fish (Salman)	25.4	13.6	0	Omega-3, Vitamin D and Potassium
Lentils	9	0.4	20.1	Iron, Folate and Magnesium
Eggs	13	11	1.1	Vitamins B12, Vitamin D and Selenium
Almonds	21.2	49.9	21.6	Vitamin E, Magnesium and Fiber
Oats	16.9	6.9	66.3	Manganese, Phosphorus and Zinc
Rice (brown)	2.6	0.9	23.5	Magnesium, Selenium and Vitamin B
Broccoli	2.8	0.4	6.6	Vitamins (C and K) and Folate
Avocado	2	15	9	Potassium, Folate and Vitamin E
Quinoa	14.1	6.1	21.3	Magnesium, Iron and Vitamin B
Spinach	2.9	0.4	3.6	Iron, Calcium, Vitamins (A and K)
Sweet potatoes	1.6	0.1	20.1	Vitamin (A and K) and Potassium
Cheese	24.9	33	1.3	Calcium, Vitamin B12 and Phosphorus
Tuna	30	1	0	Omega-3, Vitamin D and Potassium
Tofu	8	4.8	1.9	Calcium, Iron and Magnesium

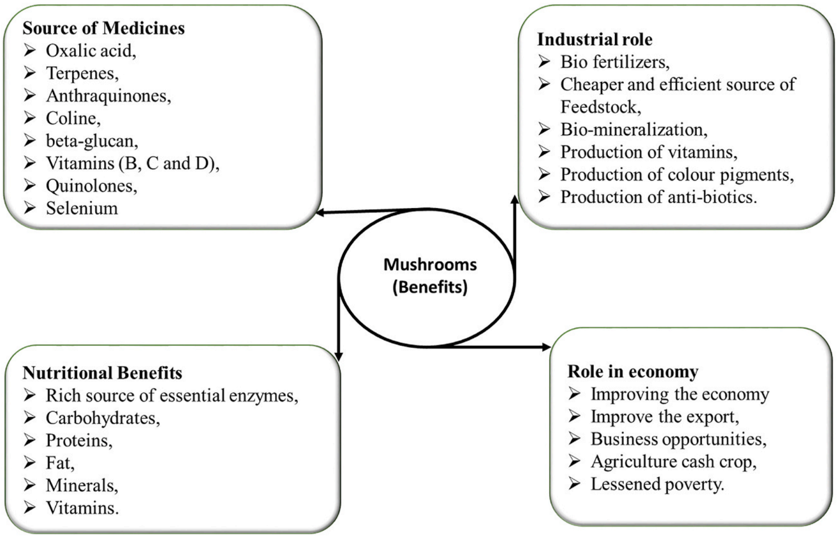

Fig. 3. The importance and benefits of mushrooms are presented in different aspects of life and its economic role in the country [11].

represented by glucose, mannitol and α-trehalose, respectively [57]. Similarly, the crude fibers in the mushrooms in the form of indigestible carbohydrates have beneficial effects on human health, like improving intestinal tract function and lowering blood glucose and cholesterol levels [58]. β-glucans (such as lentinan, pleuran, ganoderan, etc.) possess several positive health effects (immuno-modulatory, antimicrobial, antiviral (in particular *anti*-HIV), anti-inflammatory and anticancer properties, etc.) [59,60]. Mushrooms are also rich in trehalose, known to synthesize stress-responsive factors in human cells when exposed to environmental stresses like heat, cold, oxidation, etc., retaining cellular integrity [61].

As a rich source of dietary fibers, mushrooms helps the human body to maintain a good state of health by improving the immune system to combat diabetes, cardiovascular pathologies, cancer, and obesity [62–64]. Similarly, proteins are another important component of dry matter contributing to the high nutritional values of mushrooms compared to other foods such as meat, eggs and milk [65]. The nine essential amino acids required by the human body are part of the mushrooms' composition, so they may be proposed as a viable dietary alternative for vegetarians and vegans [66].

Mushrooms also contain important macro and micro elements, such as potassium (K+), phosphorous (P^+), calcium (Ca^{2+}), magnesium (Mg^{2+}), and iron (Fe^{2+}) [67]. The content of these nutrients are much higher in mushroom than those of most vegetables, fruits, meats and cereals etc. [68]. On the other hand, Na^+ content is very low, making mushrooms a prosperous source to prevent hypertension, particularly for the people recovering from this medical condition [69,70].

3.3. Medicinal properties of mushrooms

During the physio-chemical process, the living organisms generate free radicals in the form of reactive oxygen species by-products, due to which mediators directly or indirectly affect the body's normal physiological and biochemical functions [31,71,72]. Among all, nitric oxide (NO) and other prostaglandins are derived from the immune cells i.e., and bradykinins are mainly derived from circulation, while protons are developed by cell destruction (Fig. 3). These all cause oxidative damages that result in aging, atherosclerosis and

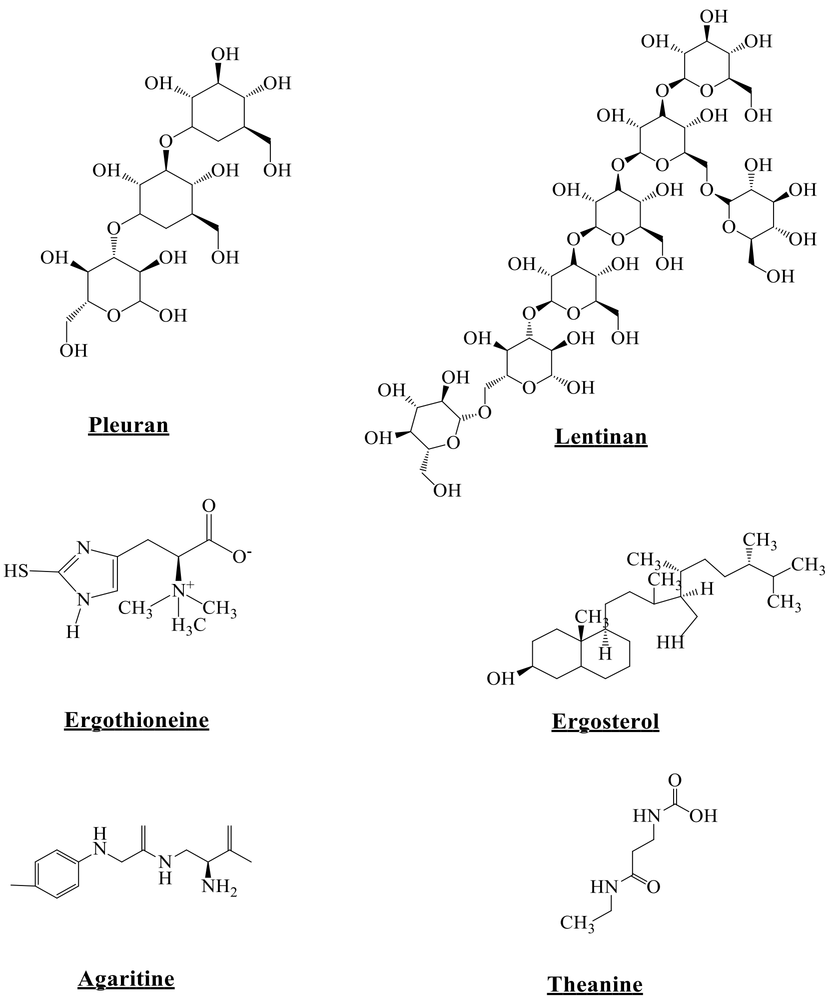

Fig. 4. Chemical structures of isolated biochemical from edible mushrooms with potential to prevent different disorders.

cancer [73]. During these circumstances, the antioxidant defense mechanism in humans and other organisms cannot efficiently repair the body to the normal state or prevent the damage been caused [74]. Alternatively, the use of nutritious diets have a pivotal role in overcoming such damages to the body [75].

Recently some natural antioxidants have been isolated from various resources like plants (spices, leaves, fruits, flowers, seeds, cereal crops, vegetables, roots, and herbs), mushrooms and algae [76,77]. Currently, medicinal mushrooms, i.e., *Ganoderma lucidum*, *Ganoderma tsugae*, *Murrill*, and *Coriolus versicolor* commonly used for pharmaceutical purposes and nutritive food in China and Taiwan [78]. These species are of key importance due to the presence of medicinally active ingredients in various therapeutic effects like chronic bronchitis, anti-tumor, antioxidant, anti-cancer alignments, and anti-mutagenic with the least side effects [79]. The precious bio-active and antioxidant compounds (aldehydes, free amino acids, soluble sugar, octenes, ketones, sugars, terpenes, alkaloids, phenols, carotenoids, vitamins glutathione and flavonoids) in mushrooms are mainly responsible for curing such disorders [80–82]. These compounds directly and indirectly regulate a wide range of biological processes like enzyme inhibitory activities (i.e., tyrosinase inhibition), metal chelation, and inhibition of lipids peroxidation [83].

Similarly, mushrooms possess terpenes, chitosan, and sterols, that actively play a role in obesity, respiratory, cardiovascular and neurodegenerative diseases, and have anti-cancer, antimicrobial, anti-arthritis, anti-diabetic modes of action [4,84–86]. Besides, edible mushrooms contain several primary vitamins like vitamins A, B, C, and riboflavin as compared to other vegetables and fruits (Fig. 4) [59,87]. Additionally, mushrooms are well characterized by low crude fat content, with a prevalence of polyunsaturated linoleic acid and mono-unsaturated oleic acid, followed by linolenic and palmitic acids, thus mushrooms are suitable for a low-calorie diet [88,89].

3.4. Antioxidant activities

The overproduction of free radicles (superoxide anion radical, hydrogen peroxide, hypochlorite, nitric oxide and peroxynitrite radicals) in the body causes significant disruption of DNA, proteins, carbohydrates, lipids and mandatory enzymes. These drastic changes in turn leads to cancer, cardiovascular, inflammatory and neurodegenerative diseases [90–92]. However, different natural products like cereals, grains, edible mushrooms, vegetables, medicinal plants and fruits contain rich natural antioxidants which can capture free radicles and could be used to prevent disorders caused by oxidative stress [93,94]. Among all, the notable medicinal properties of edible mushrooms and antioxidants activities, like reduction of low-density lipoproteins in human and lipids peroxidation scavenging of free radicles etc., have been well studied recently [95,96]. The mushrooms' polysaccharides are usually considered as one of the most important contributors to antioxidant activities [97]. *Inonotus obliquua* was investigated in the antioxidant bioassay and acid protein-bound water-soluble polysaccharide with a molecular weight of 17 kDa, and its neutral protein, uronic acid and sugars contents showed 18.5 %, 6.1 %, and 42.5 %, inhibition, respectively [98]. It was concluded that the polysaccharides showed a significant inhibitory effect proven by concentration-dependent reduction of hydroxyl radicals and DPPH bioassays. Similarly, they also noted that polysaccharides significantly inhibited the formation of ascorbate-induced lipids peroxidation in the rat liver via; *in vivo* approach [99,100]. The crude polysaccharides isolated from the four major edible mushrooms (*Flammulina velutipes*, *Agaricus bisporus*, *Lentinus edodes,* and *Auricularia auricula*. *Agaricus bisporus*) was noted as the best natural antioxidant source.

3.5. Anti-inflammatory activity

Medicinal mushrooms have been considered as one of the most important components of traditional Chinese herbal medicines since ancient times [101]. For example, *cordyceps sinensis* mushroom was used as a functional food and herbal recipe for a long time in China [102]. The anti-inflammatory effects of *cordyceps sinensis* was studied [103] in rat by *in vivo* approach [104,105] and it was identified that cordymin (peptide) is mainly responsible for its anti-inflammatory property. The mushroom-produced cordymin also affected the antioxidant and cytokine levels in the *in vivo* and *in vitro* assays, respectively, where level of interleukin-1 beta (IL-1β), tumor necrosis factor-alpha (TNF- **α**) and total antioxidant were significantly decreased [106]. Cordymin also significantly dose-dependently inhibited the acetic acid-induced abdominal compressions in mice [107].

Similarly, Shao et al. [108], investigated other polyphenol components like hispidin was isolated from the medicinal mushroom, *Phellinus* which also possess significant biological properties. The findings revealed that hispidin inhibits the transcriptional expression of NF-κB and also significantly diminished LPS-induced NF-κB nuclear translocation and other mandatory inhibitors of IêB-á deprivations. Furthermore, hispidin can reduce iNOS protein expression to some extent and the generation of ROS (reactive oxygen species) in the LPS-induced cells, but the phosphorylation of mitogen-activated protein kinases was not affected. These findings confirmed the anti-inflammatory effects of hispidin by suppressing the ROS-mediated NF- κB signal transduction pathway.

3.6. Immunomodulatory activity

Immunomodulatory activity is one of the most important traits to protect humans from different diseases [109]. Additionally, medicinal plants and mushrooms like *Lentinus edodes*, *Ganoderma lucidum*, *Schizophyllum commune,* and *Grifola frondosa* are considered as the primary, rich, and natural resources of the immunomodulatory mediators [110,111]. The presence of bioactive compounds like polyphenols, proteoglycans, proteins, vitamins, and triterpenoids attributes to immunomodulatory activities of edible or medicinal mushrooms (Fig. 4) [112]. Among these diverse compounds, polysaccharides are extensively studied for their immunomodulatory effects. Panda et al. [113] isolated polyphenol from medicinal mushrooms, *Amauroderma rude,* and tested its potential in immune system regulation [114] where the crude extract of *A. rude* significantly improved the function of macrophages spleen, lymphocytes, and natural killer cells *in vitro* and increased the antibody, and lymphocyte proliferation.

The active compounds in the crude extract were isolated and identified as a polysaccharide F212 [114]. Fu et al., 2015 investigated the polysaccharides in the crude extract from *Dictyophora indusiata* and noted significant promotion in the multiplication of macrophages [115]. It was identified that the isolated polysaccharide affects the immune system by promoting the production of cytokines (IL-1, IL-6, and IL-12), nitric oxide, and TNF- α.

3.7. Anticancer activity

Cancer is one of the most mysterious death-causing diseases that vary in occurrence, form, age, and tissue type [116]. Nowadays, a prompt, safe, cheaper and effective alignment is needed for the chemoprevention of human cancer. However, natural products from vegetables, fruits, and medicinal plants, have shown significant anti-proliferative activities [117]. Several studies have confirmed that medicinal mushrooms also have a significant inhibitory effect against various forms of cancer like breast, acute leukemia, cervix, uterine, and brain cancer [118–120]. Similarly, Zhang et al. [7] investigated some species of medicinal mushrooms that contains effective anti-tumor phytochemicals [121]. Among the three triterpenoids (2, 3, 6, 2, 3-tetrahydroxy-urs-12-en-28-oic acid, lupeol and 2, 3, 23-tryhydroxy-urs-12-en-28-oic acid) isolated from *Pleurotus eryngii,* 2, 3, 6, 2, 3-tetrahydroxy-urs-12-en-28-oic acid, and lupeol showed effectiveness in controlling the breast cancer in MCF-7 cells lines, while 2, 3, 6, 23-tetrahydroxy-urs-12-en-28-oic acid showed significant inhibition (Fig. 5). Additionally, a carboxy-methylated p-glucan (CMPTR) was isolated from the sclerotia of *Pleurotus tuberregium* and tested on human breast cancer cell MCF-7 cell lines where CMPTR significantly inhibited the cell proliferation of MCF-7 with IC_{50} of 204 g/mL by arresting the G_1 phase of cell cycle arrest. Moreover, the CMPTR-treated MCF-7 cancer cell lines displayed declined expression of anti-apoptotic Bcl-2 protein and enhanced expression of Bax/Bcl-2 [7].

Cai et al. [123], reported that *Coriolus versicolor*'s polyphenols (CVPs) significantly inhibited the proliferation of cancerous cells. CVPs showed cytotoxic effect on human hepatoma cancer (QGY) cell lines in MTT bioassay. The cell apoptosis and cell cycle of QGY cells were checked through flow cytometry. These findings exhibited that CVPs significantly inhibited the proliferation of QGY at low concertation (>20 mg/L) with IC_{50} of 4.25 mg/L, and significant reduction was observed in the expression of important cell cycle-associated genes like p53, Fas, and Bcl-2. Similarly, Nurhayat et al., 2021 reviewed that Cuillin from the *Suillus placidus* has a key role in treating cancerous liver cells by inducing apoptosis in the human hepatoma HepG2 cells [124].

3.8. Antimicrobial potential

A number of synthetic antimicrobial mediators are already reported; however, drug resistance and toxicity are still significant hurdles to achieve the therapeutic effects [125,126]. Thus, it is very important to searcj new, useful, safe and more authentic agents for infection causing microbes [127]. Plants and mushrooms-derived chemical constituents have well-demonstrated antiviral, antibacterial, and antifungal activities. The antimicrobial effects of crude extracts of *Auricularia auricular-judae* showed inhibition against the *Staphylococcus aureus* and *Escherichia coli* [128]. The fruiting bodies of mushrooms mycelia could be functional foods and nutraceutical sources [129]. Three sesquiterpenoids and two benzoate derivatives were retrieved from the mycelia of *Stereum hirsutum*. The identified benzoate derivatives displayed antimicrobial activities against the methicillin-resistant *Staphylococcus aureus* with the inhibition of 25 μg/mL [130].

4. Mushrooms farming in neighboring countries

4.1. India

About 850 species of total mushrooms are recently identified; however, the knowledge of its medicinal and nutritional uses was there since the ancient medical treatise Charaka Samhia (3000 ± 500 BC) [131]. The scientific investigation of mushrooms in India

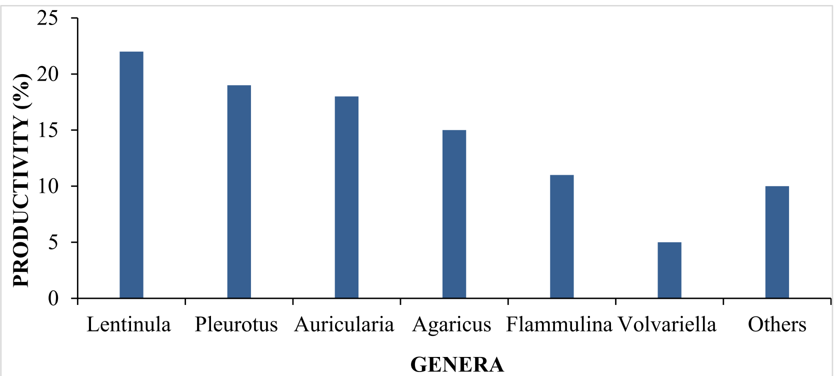

Fig. 5. The number of genus identified in Pakistan [122].

was initiated with Linnaeus's description and identification of *Podaxis pistillaris* in the 18th century that was collected and sent by Loening from the Tamil Nadu State of India [132].

It was noted that the traditional mycological information of most Indian ethnic groups has proven to be so wide and deep, utilizing approximately 283 species of the wild mushrooms from 2000 recorded globally [133,134]. Despite all favorable conditions, mushroom farming is not growing soo fast in India [135]. Currently, ~70,000 tons of fresh mushrooms are being produced in India, requiring >5 million tons of world production annually [136].

4.2. China

In recent years the usage and production of medicinal fungi in China have taken considerable attention [137]. The information of medicinal mushrooms is reported and nomenclature discrepancies are also found in several Chinese reports [138]. The available literature on medicinal mushrooms was critically reviewed and interestingly found 450 medicinal mushrooms and fungi [139]. Mushroom farming has been continuously increasing worldwide; interestingly, its annual production rate is improving by 6–7% [139]. For example, the global mushroom production in 1999 was >7 million tons, while in 2020, it was increased (double) up to 12 million tons [140]. Among all, China is one of the world's largest producers, exporters, and consumers of mushrooms, followed by Europe and Canada [60].

In China, mushrooms are ranked as the 6th most important crop as far as revenue generation for the nation is concerned [141]. The mushroom production in China was 21, 524, 473 tons [142]. During last decade, a sharp rise was seen in the diversification of mushroom species, worldwide production and commercialization accompanied by mechanization and automation [143,144]. However, mushroom cultivation and its processing have benefited millions of people in China, India, Pakistan, and other developing countries regarding social, financial, and health improvements [145]. Additionally, the cultivation and development of mushroom industries have positively impacted economic growth [20,140]. This impact of mushroom cultivations and their derivatives and products' welfare in the twenty-first century can be considered a 'non-green revolution' [140,146].

According to the CBRI (China business research institute), China is the largest edible mushroom producer across the globe, with an annual production of 38.412million tons (75 % share) in 2017 [137,147]. Additionally, CCCFNA the edible mushrooms Branch claimed that edible mushroom exports reached 3.8 billion in the successive year [148,149]. In the same way, mushroom farming is the country's fifth-largest agriculture sector, with a 24 billion USD market [150]. Based on such a tremendous amount of mushroom cultivation and production in China and India almost covering the demand of whole Asia, especially Asia-Pacific leading region production in the world markets [151]. Interestingly, the consumption rate of mushrooms is significantly increased. However, the increasing vegan population that tends toward nutrient-rich food has led to market growth in Asian countries [35].

4.3. Nepal

The consumption of wild edible mushrooms in various parts of Nepal has been in practice since ancient times [152]. Artificial farming and cultivation started in 1974, focusing on button mushroom specie farming. However, with the passage of time, the interest of the government and residents in cultivation of mushroom has increased to reduce food scarcity, medicines, and boost economy [153]. Still, there are several challenges, for example, the agro-climatic conditions, the raw material (agricultural and forest wastes etc.), efficient specie and fewer labors (with less cost). Different sectors are trying to find an efficient way to address the challenges and improve productivities [154,155]. Recently, it is observed that *Pleurotus* sp. (86 %) and *Agricus bisporus* (10 %) are already available in the market for local consumption, while other species [*Lentinus edodes* (2 %) and *Calocybe indica* (2 %)] are also cultivated at commercial-scale [62].

Concerning Nepal's current industrial status, the upward trend (30 kg in 1974 and 9300 tons in 2016) is dominated mainly by local-scale producers [156,157]. It indicates that the mushroom industries are somehow increasing in Nepal however with a slow rate [158]. One of the possible issues for this low production is seasonal weather under plastic tunnels (temporary low-cost growing mushroom houses). According to the NMPA (Nepal Mushroom Producers Association), ~2750 rural residents (labor or employees) are engaged in mushroom cultivation and other related activities [158]. The current status of mushroom production in Nepal is insufficient to meet even the local demand. In contrast, Nepal imports a significant amount of mushrooms and its products from nearby countries [157].

4.4. Diversity of mushrooms in Pakistan

A great diversity of mushrooms are found in Pakistan due to its geographical position and seasonal variation [159]. Sultana et al. [160] investigated 56 species of edible mushrooms from Pakistan (Fig. 5). Interestingly, they also reported that some important species (*Agarics Bosporus*, *Coronus comates*, *Flammulina vellutipes*, *Stropharia rugosoatnulata*, *Auricular* spp, *Pleurotus ostreatus*, *Phellurina inquinans* and *Volvariella volvacea*) were used traditionally by local inhabitants and also cultivated commercially in Pakistan and worldwide [145]. In Pakistan, mushrooms are not usually consumed as a nutritional supplement but have some traditional beliefs and are being utilized to cure several complications like cough, cancer, gastric, influenza, and hepatitis [161].

Similarly, Yasin et al. investigated 50 belonging to (24 families) of edible mushroom species from Pakistan (Fig. 6) [162]. They found that the majority of these mushrooms were wild (62.9 %), followed by cultivated (37.10 %), toxic (11.75 %), while some species were of unknown information.

4.4.1. Mushrooms status and cultivations methods in Pakistan

In Pakistan, mushroom cultivation is gaining momentum as an alternative agricultural practice due to its potential economic, nutritional and environmental benefits [163,164]. Mushroom cultivation in Pakistan has been steadily increasing in recent years, driven by rising consumer demand, growing awareness of the health benefits and the availability of suitable substrates for cultivation [163,165]. Similarly, mushroom cultivation is still relatively small-scale compared to other agricultural sectors in Pakistan, there is growing interest among farmers, entrepreneurs, and researchers in exploring the potential of mushroom farming as a viable livelihood option and sustainable agricultural practice [145,163].

Mushroom cultivation in Pakistan typically involves preparing substrates using agricultural waste materials such as wheat or rice straw, cotton waste, sugarcane bagasse, or sawdust [163]. These substrates are supplemented with nutrients and sterilized to create an ideal growing medium for mushroom mycelium [163,166,167]. Once the substrate is prepared and sterilized, it is inoculated with mushroom spawn, which contains the vegetative mycelium of the desired mushroom species. For example, the pasteurized substrate is spawned and adequately packed in polyethylene bags of approximately 30 cm wide and 60–~90 cm long for oyster mushroom bag culture. For more quantitative and qualitative production, the room's temperature and humidity should be 18–27 °C and 75 %, respectively. Typically, about six flushes could be obtained from each bag, and the first three are of key importance in commercial production. It has been noted that for every 10 kg of dry substrate used, as much as 15–22 kg of mushrooms can easily be harvested from the first 3–4 flushes. Spawn can be obtained from commercial suppliers or produced in-house using sterile techniques. The inoculated substrate bags or trays are placed in a controlled environment with optimal temperature, humidity, and ventilation for mycelial growth [163,168]. During the incubation period, the mycelium colonizes the substrate, after which fruiting conditions are induced to stimulate mushroom formation [163,169]. Mushrooms are typically harvested when they reach the desired size and maturity. Harvesting methods vary depending on the mushroom variety but generally involve gently twisting or cutting the mushrooms from the substrate [163,170]. Proper post-harvest handling is essential to maintain the quality and shelf life of the mushrooms. Different varieties of edible mushrooms have been investigated and cultivated in different provinces of Pakistan (Fig. 6) [144].

5. Mushrooms farming

The rapid increase in the world's population, drastic decrease in the per capita arable land, rapid urbanization, industrialization and climate changes, has increased the demand of good quality functional foods (Fig. 7) [171]. Nowadays, scientists are focusing on several novel and secondary crops, including mushrooms [172]. Mushroom farming is an indoor activity and can be cultivated in a limited space and land to get more production. Mushroom cultivations are an essential part of sustainable agriculture and forestry [173]. An enormous amount of organic wastes are generated from agriculture, and food processing. Mushroom farming can improve the livelihood of marginal farmers by generating constant farm income and helps to reduce poverty (Fig. 8) [174,175]. As per availability of labors and land, the cultivation can be at larger or small scales; interestingly, it could be cultivated on a part-time basis with minor maintenance [176]. Furthermore, mushroom cultivation also improve the sustainability of small-scale farming systems by recycling the organic waste matter, which can be used as a growing substrate, just like a fertilizer [37,177]. Mushroom cultivation is one of the most important source having potential to process and recycle such waste materials i.e., plants/crop residues, into valuable food stuffs for the betterment of humans, plants, and other animals [13,30].

During mid of twentieth century, rapid change has been observed in the production of several species of mushrooms like shiitake, wood ear, oyster and Flammulina at commercial level [178]. Besides, its nutritive demand, the trade of mushroom has also been increased over the last few decades due to presence of important phytochemicals that can be used for therapeutic purposes for different disorders [179].

5.1. Substrate selection

The choice of substrate, the material upon which mushrooms grow, is a cornerstone of successful cultivation and production,

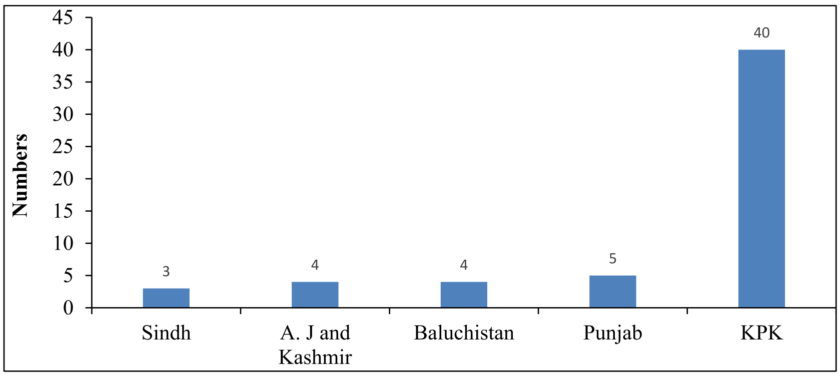

Fig. 6. Diversity of edible mushrooms across different regions of Pakistan.

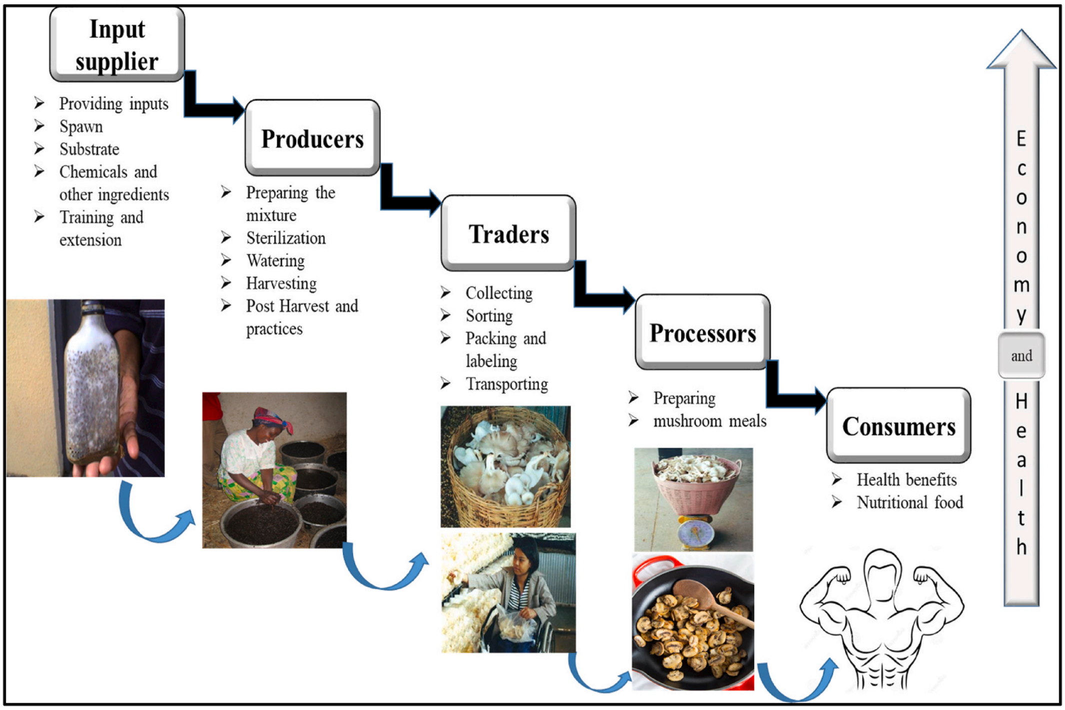

Fig. 7. Proposed model for the cultivation and processing of mushroom on industrial scale is shown.

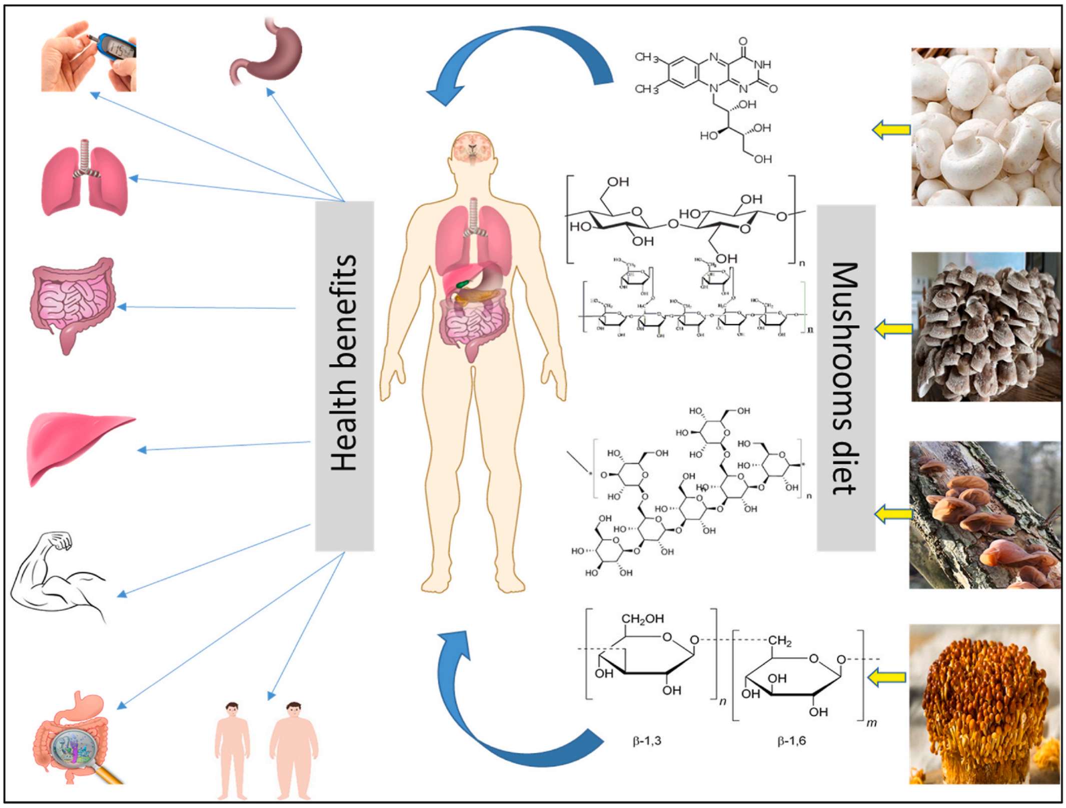

Fig. 8. Different nutritional and health scenarios of edible mushrooms are shown.

impacting both the quality and quantity of the yield [180]. Agricultural by-products such as straw, sawdust and various organic residues are commonly utilized as substrates due to their availability and suitability for mushroom growth [181,182]. However, recent innovations in mushroom cultivation have focused on optimizing substrate composition and supplementation, as well as exploring alternative materials to further enhance nutritional content and increase yield potential [183]. Researchers have delved into novel approaches aimed at improving substrate quality and nutrient availability, with studies by Royse [184] and Nandi et al. [185] shedding light on these advancements and their implications for modern fungiculture practices. Through ongoing research and innovation, the mushroom cultivation industry continues to evolve, striving to maximize productivity while ensuring sustainability and environmental responsibility.

5.2. Inoculation

Inoculation marks the initial step in introducing mushroom spores or mycelium into the prepared substrate. This process, known as the spawn run, involves the colonization of the substrate by the mycelium [186]. Modern techniques, which include the use of high-quality spawn and stringent aseptic practices, significantly improve the efficiency of inoculation and promote robust mycelial growth [187]. These contemporary methods play a crucial role in ensuring successful cultivation and maximizing yield potential in mushroom production [140].

5.3. Quality control and disease management

Mushrooms are highly sensitive to environmental conditions, particularly temperature, humidity and light [188]. Recent research highlights the importance of controlled environments, such as climate-controlled grow rooms or polyhouses, in precisely regulating these factors to optimize yield and quality [188]. By carefully managing environmental conditions, growers can create ideal settings for mushroom growth, resulting in higher yields and superior product quality.

Mushrooms are susceptible to various diseases and pests, posing significant risks to yields [189,190]. Recent studies delve into integrated pest management strategies, biocontrol methods, and the breeding of disease-resistant strains to mitigate these risks [191]. By employing a combination of approaches, growers can effectively manage pests and diseases, safeguarding their mushroom crops and ensuring sustainable production practices [192].

5.4. Harvesting

Efficient harvesting and proper post-harvest handling play vital roles in maximizing both the yield and quality of mushrooms cultivated in polyhouses [193]. The optimal harvesting time depends on the maturity and size of the mushrooms, with harvesting too early or too late impacting both quantity and quality. It is generally recommended to harvest mushrooms when the caps are fully expanded but not yet flattened, with maturity indicators such as the veil breaking for *Agaricus bisporus* species guiding harvest timing [194]. Uniform harvesting across the cultivation bed ensures consistent quality, with mushrooms of similar size and maturity typically harvested together to streamline post-harvest handling and packaging [195]. Harvesting frequency varies with the mushroom species, with some producing multiple flushes, necessitating regular harvesting intervals as new mushrooms reach optimal maturity. Monitoring primordia and pins' development aids in determining the appropriate timing for subsequent harvests [196].

5.5. Storage

Following harvesting, mushrooms must undergo rapid cooling to prolong shelf life, with the recommended storage temperature for most species ranging from 0 to 4 °C [197]. Alam et al. [198] stress the importance of maintaining high humidity levels during storage to prevent dehydration and preserve quality. Proper packaging is crucial to shield mushrooms from physical damage and maintain freshness, with packaging materials requiring some airflow to prevent moisture buildup and subsequent bacterial and fungal growth. The industry is increasingly exploring sustainable and eco-friendly packaging options. Additionally, value-added processing methods, such as drying, can extend shelf life and create new marketable products. Techniques like freeze-drying or hot air-drying preserve the mushrooms' nutritional value while enhancing storage stability [199,200].

5.6. Marketing

Anticipated yield and market prices for mushrooms are pivotal considerations in conducting a cost-benefit analysis [201]. Continuous monitoring of cultivation practices, environmental conditions and crop health is essential for maximizing yield potential. Staying abreast of market demand and price fluctuations assists in making realistic revenue projections [202,203]. Evaluating the return on investment is critical, involving a comparison of total revenue generated from mushroom sales against total investment and operational costs. Understanding the payback period and potential profit margins offers valuable insights into the financial sustainability of polyhouse cultivation ventures [204].

5.7. Conditions for mushroom farming

Controlled climatic conditions are paramount in mushroom cultivation, impacting growth, development and yield across various stages [182,188]. Temperature regulation is critical, as fluctuations affect mycelial growth, pinning and fruiting, with research indicating that specific temperature ranges enhance efficiency and yield [197]. Humidity management is equally crucial, influencing fruiting body formation and mushroom quality, with precise control necessary for optimal cultivation [205]. On the same way, carbon dioxide (CO_2) levels must be controlled, especially during fruiting, to prevent impediments to fruiting body formation, with advancements in climate control systems proving effective in enhancing yields [206]. While mushrooms don't require light for growth, controlled light conditions during pinning and fruiting stages ensure uniform development, preventing irregularities in shape and size [207]. Controlled environments also aid in pest and disease prevention, creating inhospitable conditions for pathogens and pests, supporting sustainable cultivation practices [208,209].

6. Nutritional and therapeutic values of mushrooms

In addition to its natural flavor and texture, mushrooms are also well known for their nutritional and chemical properties (Fig. 8) [210]. Conferring to the Global Hunger Index (GHI, 2019) statement, most Asian and African countries are continuously facing malnutrition and hunger [211]. Similarly, United Nations' Sustainable Development Goals (SDGs) also require prompt support from developed country's governments to end hunger, achieve food security, and improve nutrition for the poor and vulnerable societies by 2030. According to WHO (2020), ~690 million people worldwide do not have enough food to lead an everyday life [212]. Among them, Asia has the highest ratio (381 million), followed by Africa (250 million), Latin America, and the Caribbean (48million) [213].

Cultivation of the mushrooms at large scale is one of the best solutions to overcome food scarcity because of its higher nutritional content like proteins, minerals, vitamins A-K and low fat contents [35]. Moreover, edible mushrooms also serve as a best option for the people who do not eat animal proteins due to religious believes or health conditions [214]. It could regulate and overcome protein deficiencies and supplement with cereals. Like the animal proteins, mushroom also contains same kind of nine (9) essential amino acids (EAAs), while the plant-based protein sources normally lack one or two EAAs. Mushrooms have high branched-chain amino acid (BCAA) components, usually only present in animal-based protein sources [215].

7. Food security assurance

Food is one of the basic needs of life that provides energy to cell/body to perform all essential life activities [216]. When "all men, with bodies, economically and socially have access to safe, adequate and nutritious food that meets their all dietary needs, health and wellness requirements and food preferences active life and the four pillars food security is availability, access, use and stability [217]. However, the fundamental and right understanding of people's concerns about nutrition, medicines, and economic properties of mushrooms and their cultivation on an industrial and household scale, where mushrooms meet all basic requirements for food security [218,219]. Humans have been dealing with multi-year hunger and food shortage due to various determinants of low agricultural production [220]. The main possible concern about this issue is that the population increases very rapidly; desertification and urbanization make this situation more serious [221]. This problem is quite severe in African and Asian developing countries. In 2009, Chief Scientific Adviser, UK Government, Professor John Beddington, warned that population is increasing, and energy reserves are drastically decreasing, lack of food creates water and energy shortages by 2030 [222]. Similarly, in 2019, ~750 million people (one in ten people worldwide) faced severe food insecurity (World Health Organization, 2020) [223].

It has been observed that in the poorest households especially in Pakistan, caloric intake falls significantly below recommended levels, with wheat and rice being the primary sources of calories [223,224]. Moreover, dietary diversity is limited, especially among rural and poor populations [223,225]. The national nutritional survey highlights that limited and less diverse diets contribute to micronutrient deficiencies, adversely affecting the growth, immunity, and cognitive development of children in Pakistan [223,226]. Data reveals alarming rates of anemia, with approximately 30 % of children and 50 % of females affected. These high rates of hidden hunger are likely linked to poverty-driven dietary patterns [223,226]. At the household level, food insecurity emerges as a fundamental determinant of maternal and child undernutrition. Pakistan, previously self-sufficient in wheat and rice production, experienced a decline in grain production post-1980 [223,227]. This decline was exacerbated by a global decrease in food prices, leading to reduced demand for grains and consequent underinvestment in the agricultural sector [223,228]. Despite a global increase in food grain prices in 2007, Pakistan was pressured by international financial institutions to export its limited wheat surplus [223,229]. Furthermore, leasing agricultural lands to foreign countries and agribusiness investors resulted in the outflow of grains to investing nations. Insufficient policy measures were taken to address the escalating food prices, with wheat prices rising significantly from RS. 400/40 kg in 2004 to RS. 630/40 kg in 2008, and exceeding 1400/40 kg later [223,230,231].

Environmental pollution has escalated significantly in recent years, reaching levels in certain areas that pose toxic threats to living organisms [223,232]. Among various types of pollutants, toxic heavy metals and metalloids represent some of the most significant threats to biological systems [233,234]. Unlike organic pollutants, which can biodegrade into less harmful substances, heavy metals cannot undergo degradation into safer end products [233,235]. While low concentrations of certain heavy metals are necessary for biological functions, metals such as mercury (Hg), arsenic (As), lead (Pb), and cadmium (Cd) are both biologically non-essential and highly toxic to living organisms [233,236]. Even essential metals can become toxic when present in concentrations exceeding permissible levels [31,233]. Additionally, estimates suggest that approximately 40 % of irrigated land in Pakistan has been impacted by waterlogging and salinity issues, largely attributed to excessive irrigation practices. With irrigation fees remaining low and unrelated to actual water consumption, farmers tend to overuse available water resources, leading to waterlogging, soil degradation, and diminished productivity [233,237]. Additionally, despite a higher-than-average consumption of fertilizers per hectare in the country (approximately 133 kg compared to the world average of 94.1 kg/ha), crop yields remain significantly lower. This situation not only reflects resource inefficiency but also raises concerns about potential pollution hazards [233,238].

Due to the growing human demand of protein rich foods, the alternatives of traditional are developed to produce inexpensive and protein-rich food [233]. Farming edible mushrooms is the best, easy and efficient alternative. Mushrooms are an indoor crop, which can be easily grown vertically to use less land space. It is recognized as the largest protein producer per unit area and time, nearly 100 times higher than typical agricultural practices [35]. Mushrooms are superfoods and one of the healthiest foods in the world, and approximately 50 % of edible mushrooms are considered as 'functional food' in addition to essential nutrition. They have potential beneficial health effects (Food Revolution Network 2016). Recently, Chinese have identified 966 types of edible fungi and 576 kinds of dietetics [150]. Nearly 70 species can be cultivated locally, and 18 can be cultivated industrially [239]. According to such observation, the mushrooms industry could exceed 25 million tons globally.

Nowadays, mushroom cultivation is going on in more than 100 countries, whose production is rising by 6–7% per year [240]. In some of the developed countries of Europe and America, mushroom farming is guaranteed by high-technology industry mechanization and automation [75]. However, 'Asia Pacific' is the leading region for mushroom production in the world's market. For example, China, currently is the largest mushroom producer, has reached >20 million tons and meets >80 % of the world's mushroom production [241].

8. Policy implication

8.1. Opportunities

Mushrooms are declared as a good and cheaper food source [242]. The high nutritional values attracts the low income or poor people to cultivate it in order to strengthen livelihood security in a brief time [243]. Its local cultivation and acquired knowledge allows the cultivators to provide consistent and predictable qualities and quantities of mushrooms to invite more buyers easily [244].

- **Growing Demand**: There is a growing demand for mushrooms worldwide due to their nutritional value, unique flavors, and culinary versatility. This demand presents a significant opportunity for mushroom farmers to capitalize on a lucrative market.
- **Health and Nutrition:** Mushrooms are rich in protein, fiber, vitamins, and minerals, making them a popular choice for health-conscious consumers. With increasing awareness of the health benefits associated with mushroom consumption, there is a growing market for both fresh and processed mushroom products.
- **Diverse Product Range**: Mushroom farming offers opportunities to produce a wide range of products, including fresh mushrooms for culinary use, processed mushrooms such as canned or dried mushrooms, mushroom extracts for supplements or medicinal purposes, and value-added products like mushroom-based snacks or seasonings.
- **Year-Round Production**: Mushrooms can be cultivated year-round in controlled environments, providing a consistent and reliable source of income for farmers regardless of seasonal variations in traditional crop production.
- **Utilization of Agricultural Waste**: Mushroom cultivation often involves using agricultural waste materials such as straw, sawdust, or spent compost, providing an eco-friendly solution for waste management while simultaneously producing a valuable crop.
- **Small-Scale and Urban Farming**: Mushroom farming can be done on a small scale and in urban environments, requiring relatively little space and initial investment compared to traditional agriculture. This makes it accessible to smallholder farmers and urban entrepreneurs looking to diversify their income streams.
- **Employment Opportunities**: Mushroom farming can create employment opportunities, particularly in rural areas where job opportunities may be limited. From mushroom cultivation and harvesting to processing and marketing, the industry supports a range of jobs along the value chain.
- **Value-Added Products and Innovation**: There is potential for innovation and the development of value-added mushroom products, such as gourmet mushroom varieties, functional foods fortified with mushroom extracts, or sustainable packaging solutions, catering to niche markets and consumer preferences.
- **Export Potential**: With increasing global demand for mushrooms, there are opportunities for mushroom farmers to tap into export markets, particularly for high-quality specialty mushrooms or processed mushroom products.
- **Government Support and Policies**: Many governments provide support for mushroom farming through subsidies, training programs, research funding, and policy incentives aimed at promoting agricultural diversification, food security, and rural development.

8.2. Challenges

One key difference between the local and advanced mushroom farming is enhancement and control. The basic challenging factors includes selection of species, a substrate used, climatic conditions, market demands, and labor management (training). Compared to developed countries like China, Japan, USA and European countries, these challenges are fully satisfied. However, developing countries like India, Bangladesh, Pakistan, and Nepal have faced several issues mentioned below.

- **Infrastructure and Technology**: Limited access to suitable infrastructure and technology for mushroom cultivation, including temperature-controlled growing environments, sterilization equipment, and spawn production facilities, hinders the growth of the mushroom industry in Pakistan.

- **Quality Control and Standards**: Inconsistent quality control measures and adherence to international standards for mushroom production pose challenges in accessing export markets and maintaining consumer confidence in domestically produced mushrooms.
- **Limited Awareness and Education**: Lack of awareness about the benefits and techniques of mushroom cultivation among farmers and the general population is a significant challenge. There is a need for educational programs and training initiatives to disseminate knowledge about mushroom farming practices and their potential benefits.
- **Availability and Cost of Inputs**: The availability and cost of inputs such as mushroom spawn, substrate materials, and equipment can be prohibitive for small-scale farmers, limiting their ability to adopt mushroom farming as a viable livelihood option.
- **Climate and Environmental Factors**: Pakistan's diverse climate and environmental conditions present challenges for mushroom cultivation, particularly in regions with high temperatures or humidity levels. Climate variability and extreme weather events can impact mushroom yields and production consistency.
- **Pests and Diseases**: Pest and disease management is a significant challenge in mushroom farming, with pests such as mites, flies, and nematodes, as well as fungal diseases, posing threats to mushroom crops. Integrated pest management strategies and disease prevention measures are essential to mitigate these risks.
- **Market Access and Distribution**: Limited market access and distribution networks for mushrooms, especially in rural areas, restricts the market reach of mushroom farmers and may result in price fluctuations and income instability.
- **Policy and Regulatory Framework**: Inadequate policy support and regulatory frameworks for mushroom farming, including land tenure issues, licensing requirements, and taxation policies, create barriers to entry and inhibit the growth of the mushroom industry in Pakistan.
- **Competition and Market Dynamics**: Competition from imported mushrooms and other agricultural products, as well as fluctuating market prices and demand dynamics, add to the challenges faced by mushroom farmers in Pakistan.
- **Socio-economic Factors**: Socio-economic factors such as gender disparities in access to resources and decision-making power, as well as limited access to credit and financial services for small-scale farmers, exacerbate the challenges of mushroom farming in Pakistan.

8.3. Government policies

1. Based on the public point of view, delivering public goods, including rural markets, roads, electricity, and telecommunications, can be considered the trade ecosystem that directly improves and enhances the small scale of trade and their livelihood. As their interest and capabilities increase, efficiency, risk, cost, and vulnerability decrease. To import/develop an appropriate technology based on the local needs and agro-climatic.
2. To develop or import the appropriate technology based on local needs and agro-climatic conditions.
3. To find a better substrate readily and locally available
4. To establish mushroom culture centers and advanced technological intervention of spawn production centers.
5. To facilitate and provide better quality spawn at a low cost.
6. To train the grower's knowledge and skill in on-farm sanitation and other disease integrations.
7. The knowledge of values-added chain of the mushrooms should be spread from the farm to the final consumer via; ICT (Information and Communications Technology), TV (Television), Radio, New papers, advertisement, posters, workshops, and festivals.
8. To provide financial support to small and medium-scale enterprises.
9. To create awareness among the local people about mushroom farming with food, health, and medicinal standards. The quality and quantity of foodstuffs is increasing worldwide in domestic and global markets. There is an immediate need to build some databases for online marketing to fulfil the demand. For example, in China, 'Alibaba' played a key role in mushrooms and other foods.
10. To improved future sales by enhancing the public awareness of environmentally friendly farming by utilizing crop waste and spent mushroom substrate as value-added products.
11. Mushroom farming is labor intensive, which is appropriate for rural and urban dwellers.
12. Mushroom farming creates self-employment for female and elderly persons.

9. Future trends

Mushrooms can be an important ingredient for rural and semi-urban populations for food security and income generation. In contrast, mushrooms can be used as food additives because of protein and mandatory micronutrient contents, and medicinal properties. Due to high medicinal and nutritive values, inexpensive, easily cultivatable, remediate the agro waste, and friendly weather makes well the adaptation of mushrooms. Gupta et al., 2018 explained the concept of mushroom cultivation as social group development, valuable and small-scale innovations. Recently, FAO (Food and Agriculture Organization) has been enthusiastically sponsoring the cultivation of mushrooms, especially in developing countries. Pakistan has tremendous potential to cultivate and produce edible/medicinal mushrooms, even at commercial. However, unfortunately, Pakistan is not yet a major producer of any mushroom variety. Due to the diverse climatic conditions, the cultivation of some edible or medicinal mushrooms is carried out in different parts of the country on a local scale.

One possible reason for the demand and supply gap in the trade of mushrooms is the shrinkage of assembly of Western countries, and higher labor charges have stemmed higher market prices for Asian countries like China, Pakistan, India, and Bangladesh. However, to be successful in both export and domestic markets, it is important to produce fresh, quality and fortified value-added mushrooms products at competitive rates. Moreover, efforts should also be taken to exploit the commercially used mushrooms substrate leftover after cultivation to prepare vermicomposting, organic manure, and briquettes.

Mushrooms are a functional food and a rich source of medicinally active phytochemicals that have therapeutic potential to cure several diseases. However, further investigation is required on clinical basis to confirm the medicinal values of secondary metabolites in mushrooms. Additionally, based on such assumption, it could be used daily to promote health, additive and synergetic effect of the chemical constituents present in them. Further research is needed to reveal various roles of multiple bioactive compounds.

10. Conclusion

Mushrooms stand out as a vital component of the human diet due to their exceptional nutritional value, surpassing many ordinary vegetables, dairy products, and even meat. Beyond their nutritional content, mushrooms are revered for their abundance of bioactive phytochemicals, renowned for promoting optimal health and well-being in both humans and animals. These phytochemicals have shown promising therapeutic effects in treating various ailments, including cancer, diabetes, nerve disorders, gastrointestinal issues, and combating bacterial and viral infections. Over the past decade, significant strides have been made in harnessing the potential of these bioactive compounds for nutraceutical and therapeutic purposes, with ongoing scientific validation bolstering their credibility. Additionally, mushrooms play a pivotal role in recycling crop waste materials, offering sustainable solutions in fields such as food fortification, bioremediation, and cosmeceuticals. Notably, mushrooms contribute to the production of environmentally friendly materials, including fertilizers crucial for enhancing crop yields and soil health. In countries like Pakistan, mushroom cultivation presents a compelling opportunity to address food security challenges and alleviate poverty, particularly among rural and disadvantaged communities. While some mushrooms are already cultivated on a small scale, there is an urgent need for concerted efforts to scale up production through industrialization. By embracing large-scale mushroom cultivation, we can unlock a wealth of nutritional and economic benefits, ensuring access to nutritious food and creating employment opportunities for local populations.

CRediT authorship contribution statement

Asif Khan: Writing – original draft, Methodology, Conceptualization. **Waheed Murad:** Supervision, Conceptualization. **Salahuddin:** Data curation, Formal analysis, Writing – review editing. **Sajid Ali:** Formal analysis, Data curation. **Syed Sikandar Shah:** Software, Data curation. **Sobia Ahsan Halim:** Writing – review & editing, Investigation. **Asaad Khalid:** Validation, Formal analysis, Data curation. **Hamdy Kashtoh:** Software, Investigation, Data curation. **Ajmal Khan:** Writing – review & editing, Formal analysis, Conceptualization. **Ahmed Al-Harrasi:** Writing – review & editing, Supervision, Resources.

Availability of data and materials

All datasets on which the conclusions of the manuscript rely are presented in the paper.

Ethics approval and consent to participate

Not applicable.

Consent for publication

Not relevant.

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Declaration of competing interest

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