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# Post-harvest management in mushroom production: An effective approach towards sustainability, food security and storage

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**Abstract**
Growing mushrooms has the ability to provide nutritional security and helps to reduce hunger, poverty, and malnutrition. Current agriculture situation and food production systems are under tremendous pressure from factors such as global climate change, soil and water scarcity, soil degradation, and increasing population etc. These factors threaten food and nutritional security on a regional and global scale. Additionally, improper handling of agro-industrial waste and the Crop residue burning have a harmful impact on the environment and public health. Growing mushrooms has the ability to provide nutritional security while also reducing hunger, poverty, and malnutrition. Around the world, people utilize mushrooms-a highly nutritious food-as a tonic, medication, and dietary supplement. Mushrooms are grown on lignocellulose substrates, which include crop residue, processed waste, horticultural waste, sawdust, and wood chips. As a result, high-quality food is produced from poor-quality and poor-value waste resources through mushroom farming. In this review paper, we discuss about the mushrooms current status, its production, post-harvest management using different process (physical, chemical, Thermal) and future aspects.

**Keywords:** Mushroom, climate change, hunger, nutritious, post-harvest management

## 1. Introduction
High-quality food products like mushrooms can help impoverished people in emerging nations overcome their challenges with food and nutrition. The quality of mushrooms, postharvest preservation, commercial growing opportunities, strategies for overcoming obstacles, and prospects for smallholder farming groups are all covered in this study. Plasmodial fungi, or mushrooms, are saprophytic organisms that consume decomposing organic matter. Vertical farming is a cutting-edge kind of farming that seeks to make the most use of available space. Farmers can increase the efficiency of their mushroom production by applying creative methods and the developing them vertically in stacked layers to maximize the available area as opposed to compared to conventional farming, which grows crops in huge, horizontal fields (Rahmann, 2021) [55]. Mushrooms have extremely few calories and are low in carbs and salt. Our diet's "bulk" comes from chitin, an indigestible carbohydrate that is present in mushrooms (Emberger, 2022) [17]. Mushrooms which are edible in nature and has high nutritional value are:-

## 2. Importance of Post-Harvest Management
- **Quality Preservation:** The method of preserving the freshness and quality of mushrooms after harvest is known as quality preservation. Once collected, mushrooms can quickly lose their quality due to their perishable nature. The following are a few ways to preserve mushrooms: Thermal Process, Chemical Process, Physical Process, etc.
- **Food Security:** When everyone, everywhere, has physical, social, and economic access to enough, safe, and nourishing food that satisfies what they need to eat for an active and healthy life, that state is known as food security.
- **Sustainability:** Sustainability refers to the ability to maintain or carry out a process for a

- long time. In the context of business and policy, sustainability seeks to prevent the depletion of natural or physical resources so that they can be utilized for an extended period of time.

| Mushroom (Common Name) | Bioactive Compounds | Health Benefits | References |
| --- | --- | --- | --- |
| *Agaricus bisporus* (White mushroom)  | Pyrogallol, hydroxybenzoic acid derivatives, flavonoids, lectins | Anti-inflammatory, enhanced insulin secretion, anti-ageing property | Moro *et al.* (2012) [47], Ndungutse *et al.* (2015) [48], Lakhanpal *et al.* (2005) [38] |
| *Auricularia auricular* (Jew's ear mushroom)  | Glucan, acidic polysaccharides | Immunomodulatory, anti-tumour, anti-inflammatory, lowers cholesterol and triglycerides, hypoglycaemic activity, immune tonic, and beneficial in coronary heart disease | Lakhanpal *et al.* (2005) [38], Zhang *et al.* (2007) |
| *Flammulina velutipes* (Golden needle mushroom)  | Peptidoglycan, polysaccharides, flammulin, FVP (flammulina polysaccharide-protein), proflamin (glycoprotein), a prolamin (active sugar protein) | Anti-inflammatory, antiviral, anti-tumour, antioxidant, activity, immuno-modulatory, anti-ageing property, anti-viral action | Lakhanpal *et al.* (2005) [38], Chang *et al.* (2010) [8], Chang *et al.* (2003) [5], Wu *et al.* (2010), Yin *et al.* (2010) [81] |
| *Ganoderma lucidum* (Reishi, lingzhi)  | Ganoderic acids, ganodermanontriol, ganoderiol, polysaccharides, germanium, triterpenoids, nucleotides and nucleosides, β-glucan | Anti-metastatic, anti-tumour, anti-viral, anti-HIV, immunomodulatory, antibiotic properties, liver protection, prevents cholesterol synthesis | Xu J.*et al.* (2010), Walton *et al.*(2014) [76] |
| *Lentinula edodes* (Shiitake)  | Lentinan, glucan, mannoglucan, fucomannogalactan, lentin (protein), catechinflavonoids, eritadenine | Immunomodulatory, anti-tumour, anti-inflammatory, anti-fungal, antioxidant, anti-bacterial, antifungal, antioxidant, hypolipidemic activity | Attarat *et al.* (2015) [2], Chowdhury *et al.* (2015) [10], Israilides *et al.*(2007) [32], Ngai *et al.*(2003) [49], Sasaki *et al.*(1976) [58] |
| *Cordyceps sinensis* (Caterpillar fungus)  | Cordycepin | treat lung infection, hypo-glycemic activity, cellular health properties, antidepressant activity | Moro *et al.* (2012) [47] |
| *Pleurotus florida* (White oyster)  | β-glucans | Antioxidant, anti-microbial | Ganeshpurkar *et al.* (2015) [24], Menaga *et al.* (2012) [44] |
| *Pleurotus ostreatus* (Oyster mushroom) | Functional proteins (ubiquinone-9, ubiquitin-like peptide, nebrodeolysin, and glycoprotein), proteoglycans | Immunomodulatory, hyperglycemia, anti-tumour, antioxidant, anti-viral, anti-fungal | El Enshasy *et al.* (2012) [15], Tong *et al.*(2009) [70], Chu *et al.*(2005) [11], El-Fakharany *et al.*(2010) [16], |

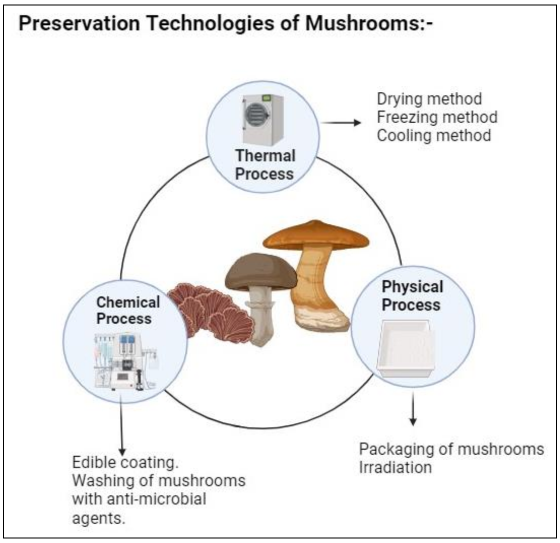
| | | | |
|---|---|---|---|
|  | pleuran (β-1, 3-glucan with galactose, and mannose), glucans, proteoglycan, laccase, pleurostrin (peptide) | | Oloke *et al.*(2015) [51] |
| *Grifola frondosa* (Ram's head)  | Lectins, polysaccharides | Decrease blood glucose improves insulin secretion and ovulation | Menaga *et al.* (2012) [44] |
| *Pleurotus pulmonarius* (Lung oyster mushroom)  | Polysaccharides such as β (1,3)-glucopyranosyl, and Polysaccharides (1,3), (1,6)-linked β-glucan | Anti-inflammatory | Lavi *et al.* (2012) [39], Smiderle *et al.* (2008) [64] |

**3. Mushroom Production: Current Status, challenges, and prospects**

In India, mushroom is growing to improve the nutrition, health, and economy of rural people. The Directorate of Mushroom Research currently oversees the small-scale button mushroom production that the United Nations Development Program started in 1974 in Himachal Pradesh (Sharma *et al.* 2017; Raut, 2019) [61, 57]. Mushroom production has grown to 42.8 million tonnes over the last 30 years, a notable 13.8-fold growth from 1990 to 2020 (FAOSTAT, 2022; Okuda, 2022) [18, 50]. China contributes more than 73% of the world's mushroom crop, which has continuously stable on its position as the top producer of mushrooms worldwide (Dimopoulou *et al.*, 2022) [13]. Nowadays, mushrooms are becoming increasingly popular over the world, with almost 100 countries growing different kinds of mushrooms (Thakur, 2020) [67]. *Auricularia auricula-judae, V. volvacea, L. edodes, Auricularia bisporus, Flammulina velutipes*, and *Pleurotus spp.* are a few of the most widely grown mushrooms in the world (Valverde *et al*., 2015; Dimopoulou *et al*. 2022) [74, 13]. The ability to consistently produce a supply of mushrooms for certain market outlets is one of the most crucial aspects of growing mushrooms for commercial use. Choosing the right mushroom to grow and locating a spawn supplier are some of the first issues faced by mushroom growers. Other issues include organizing the resources needed to build an expanding system and creating the protocols for providing different marketing channels (Raut, 2019) [57]. Therefore, the short shelf life of mushrooms and the associated problems with packaging and storage are posing significant challenges to the mushroom industry. Additional issues are the rising cost of fresh materials, the erratic and inconsistent prices, the absence of appropriate marketing structures, the quality of the spawn, mushroom cultivation regulations, minimum farm regulating practices, the scarcity of post-harvest processing methods, the protracted compost preparation, quality check and certification, the absence of transportation options, the ignorance of financial aid, and the paucity of scientific research on mushroom farming. On agricultural waste, which is available practically everywhere in the world, mushrooms can be grown. Crop waste, such as that from rice, wheat, and other crops, is a trustworthy supply. By meet the demands of world's population in terms of food, the rice-wheat cropping system (RWCS) (*Oryza sativa* L.-*Triticum aestivum* L.) is essential for maintaining global food security (Banjara *et al*., 2021) [3]. Considered the world's most technologically advanced system, the RWCS is widely cultivated. Asia grows crops on 13.5 million hectares, of which 57% are in South Asia (Ladha *et al*., 2009; Dhanda *et al*. 2022) [38, 12]. Because there are more silica particles in rice straw and there are less recycling technologies available, managing rice straw is more challenging than managing wheat straw. Crop residue burning has become a major environmental concern due to health risks and its contribution to global warming (Jayaraman *et al*. 2020) [34]. The second largest cause of global warming is the emissions of black carbon (BC) from the burning of biomass (%) (Tubiello *et al.* 2014) [72].

**4. Recent Innovations in Mushroom Preservation Technologies**

Processing of mushroom using the newest technologies available: packaging, irradiation, pulsed electric field, ultrasound, and chemical (consumable coatings, cleaning solutions, ozone, and electrolyzed water) procedure (Marcal *et al*., 2021) [44].



| **Technology used for Preservation** | **Mushroom Type** | **Storing Conditions** | **References** |
| --- | --- | --- | --- |
| Drying Preservation  | wood ear mushroom *Agaricus bisporus*, Shiitake mushroom, etc. | Temperature at 50-60°C | Fernandes *et al*. (2013) [21] |
| Cooling Preservation  | *Agaricus bisporus*, etc. | subsequent maintenance at 5 °C | Burton *et al.* (1987) [7] |
| Freezing Preservation  | *Macrolepiota procera, Agaricus bisporus, etc.* | temperature &relative humidity | Fernandes *et al*. (2013) [21] |
| Edible Coatings of Mushrooms  **Figure 37:** Mushrooms coated with the coating of sodium alginate (left) and chitosan (right). | shiitake mushrooms, *Agaricus bisporus*, etc. | storage at 4 °C, aloe-vera and gum tragacanth | Jiang *et al*. (2012) [34] |
| Washing of Mushrooms with antimicrobial agents  | *Agaricus bisporus*, wood ear mushroom etc. | $H_2O_2$ (1.5%, 2.5%, and 3.5%), citric acid (0.5%, 1.5%, and 2.5%), or EDTA (2%, 4%, and 6%), | Gupta and Bhat (2016) [28] |
| Packing of Mushrooms  | *Agaricus and Pleurotus* | polyethylene or PVC, Storage temperature of fresh mushrooms (*Agaricus bisporus*): 4 ± 1 °C and relative humidity: 85%. | Qin *et al.* (2015) [54] |

| | | | |
|---|---|---|---|
|  Irradiation | *Agaricus bisporus, Lactarius deliciosus, Boletus edulis* and *Hydnum repandum*,etc. | Irradiation at 1 kGy was the most effective | Fernandes *et al*. (2013) [21] Fernandes *et al*. (2012) [19] |

### 4.1. Thermal Process
#### 4.1.1. Drying of mushrooms
A long-term storage technique that preserves the mushrooms' freshness and enhances their flavor is drying them. Mushrooms can be rapidly dried using heat or air. Button mushrooms are hard to dry. Mushrooms can also be dried at 55-60 °C in cabinet dryers, which results in a dehydrated finished product with less moisture, a longer shelf life, and superior quality. Drying wet meaty mushrooms is a great usage for low heat. The dried mushrooms must be stored in a warm, well-ventilated area. When collected, mushrooms have 90% moisture; however, if the moisture level is reduced to 10%-12%, they can be preserved for extended periods of time (Rai and Arumuganathan, 2008) [56]. Insects and illnesses are also eliminated by the drying procedure.

#### 4.1.2. Cooling of mushroom
To eliminate field heat, pre-cooling is used. Evaporative cooling, hydro-cooling, forced-chill air, ice banks, and vacuum cooling systems can all be used to cool the mushrooms to a temperature of 2-4°C (Wakchaure, 2011) [74]. Cooling techniques such as Hydro, room, forced air, and vacuum, etc. Vacuum cooling was the most effective pre-cooling technique (Mittal *et al*., 2014) [45]. Deterioration is not occurred upto the sixth day of storage. While pre-cooling at 6-10 °C can be harmful and result in a loss of commercial value, as well as deferring the permeabilization of the cell membrane and the decay of the degree of hardness whiteness, and pH values (Xiangyou *et al*.2014) [77].

#### 4.1.3. Freezing of Mushroom
One of the greatest ways to keep mushrooms longer is to freeze them, however this process also reduces their nutritional value. One of the best methods to increase the shelf life of mushrooms and maintain their nutritional value while storing them is freezing. Furthermore, freezing preserves the color, flavor, texture, and aroma of the mushrooms better than drying does (Berna's and Jaworska, 2016; Fernandes *et al*. 2013) [4, 22]. According to Fernandes *et al*. (2013) [22], frozen *Macrolepiota procera* has less fat, carbohydrates, total sugars, tocopherols, and phenolic compounds but more protein and ash than fresh ones. This has to do with how the process of freezing alters the nutritional content of mushrooms. Reduced levels of saturated and monounsaturated fatty acids were the cause of the drop in fat content (Fernandes *et al*.2013) [22].
The quantity of vitamin A, ascorbic acid, tocopherol, carotene, and lycopene was significantly reduced by freezing, according to Berna and Jaworska (2016) [4]. Other factors that degrade the quality of nutritional and biological activity of frozen mushrooms include the method of freezing, the temperature and relative humidity during storage, the time of storage, and any pre-treatments (like blanching).

### 4.2. Chemical process
#### 4.2.1. Edible Coatings of Mushrooms
Coatings and films that are edible help to keep ascorbic acid, bioactive compounds, and total sugar well during storage. White button mushrooms can be prevented from degrading and browning too quickly by covering them with something appetizing. The edible covering completely encloses the outside of the mushrooms, retaining their quality and limiting moisture loss and gas exchange. Applying 500 mL of improved basil oil-infused Aloe-vera per liter to clean mushrooms has been shown to reduce respiration rate and maintain firmness by avoiding the buildup of malondialdehyde and relative electrolyte leakage (Mohammadi *et al*. 2021) [46]. White button mushrooms are coated with carboxymethyl cellulose and apple peel powder to preserve their quality and lengthen their shelf life after harvest (Thakur *et al*. 2021) [68].

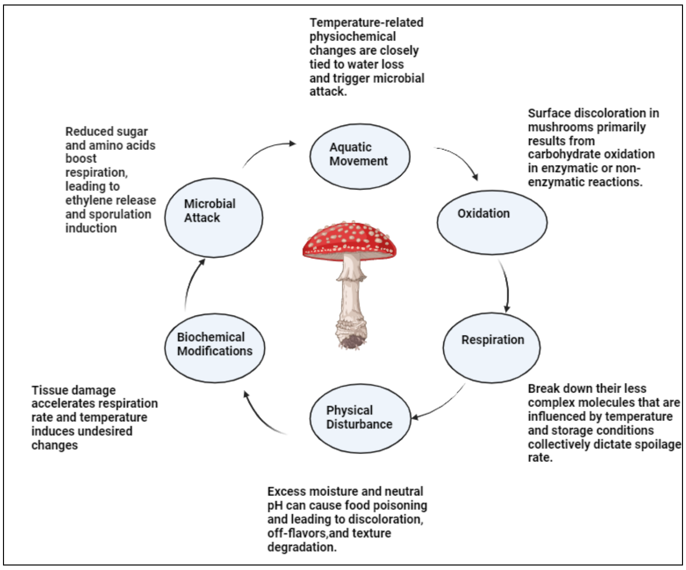
#### 4.2.2. Use antibacterial treatments to wash mushrooms.
Amino acid content is decreased by washing solutions. UV-B radiation dramatically raises vitamin D levels while gamma and electron beam radiation decrease unsaturated fatty acid levels. Usually, mushrooms are grown on compost that is slowly breaking down. In order to avoid hyphae damage, bruising, and microbial contamination, certain dirt and soil particles should be removed from the mushrooms' surface after harvest. Washing the mushrooms is therefore usually done to remove any attached dirt. Although the number of bacteria in fresh mushrooms was decreased by washing them with sodium sulfite water, browning and faster bacterial development occurred during storage compared to unwashed mushrooms (Guthrie and Bellman, 1989) [30]. Mushrooms are washed with a lowering and antibacterial solution also helps prevent browning and microbial infection. When mushrooms were cleaned with 1% citric acid, the quantity of Pseudomonas bacteria that causes bacterial blotch was decreased, but the color of the mushrooms deteriorated. Therefore, it was discovered that the best way to maintain the color of the mushrooms and reduce bacterial blotch was to wash them with 1% citric acid and then apply 1.5% sodium L-ascorbate to prevent browning (Simon and Gonzalez-Fandos, 2009) [62]. Because it inhibits bacterial activity and stops browning, hydrogen peroxide ($H_2O_2$) is believed to be useful for maintaining the color shift in mushrooms (Guan *et al*., 2013) [26]. $H_2O_2$ + UV reduced microbial loads by slowing lesion growth and prolonging button mushroom storage life without sacrificing nutritional value. $H_2O_2$ + UV could be employed to preserve postharvest quality while lowering background microbiota and *E. coli* O157:H7 populations (Sharaf-Eldin and Geosel, 2016). Guan *et al*. (2013) [26] have reported that the combination of hydrogen peroxide and ultraviolet light has been observed to decrease the microbial population, specifically *E. coli* O157:H7, and prolong the shelf life of mushrooms by minimizing lesion development without compromising the nutritional content of the mushrooms. Mushrooms were significantly less bacterial and the process of color deterioration was delayed when they were washed with oxine (50 ppm), calcium chloride (0.5%), and

sodium erythorbate (0.1%) (Wakchaure, 2011) [74].

### 4.3. Physical Process
#### 4.3.1. Packing of Mushrooms
Mushrooms quality is preserved and swelling and microbial contaminants are reduced with proper packaging. The mushrooms underwent thorough cleaning prior to being placed in polypropylene packaging. The mushrooms were rinsed with 0.5% $CaCl_2$ + 5% KMS + 0.5% NaCl, and after three days in both ambient and refrigerated conditions, they kept a suitable texture and color (Singh *et al*., 2016). Mushrooms may suffer physical and chemical deterioration if they are stored in active containers supplemented with acai extract and zeolite for 28 days at 4 °C after harvest. Mushrooms kept in active packaging, especially those with zeolite, have increased levels of vitamin C and antioxidant capacity (Hanula & colleagues, 2021) [31]. As stated by The Mahajan group (2008) mushrooms need to be packed at a humidity of 96%; the recommended humidity range for the best color is 87-90%. Wakchaure (2011) [74]. The altered atmospheric package has been utilized extensively in mushroom packing because it inhibits browning and slows down certain metabolic processes. Many factors, including permeability, packaging material, depth, and product weight, need to be taken into account while constructing a specific atmospheric packaging (Palacios *et al*. 2011) [52]. By using micro-perforated films and high oxygen levels, color and volatile components were retained, preserving the color and gaining customer acceptance. It also prevents water condensation and unwanted volatile chemical production inside mushroom packaging, but studies have shown that it lowers pH levels (Pogorzelska-Nowicka *et al*. 2020) [53]. In the case of polythene bags of thick 100 gauges with a 0.5 percent leaking area for storing mushrooms in refrigerated settings, an environment of 2.5-5% $CO_2$ and 5-10% $O_2$ is advised for the storage of mushrooms (Wakchaure, 2011) [74].

#### 4.3.2. Irradiation
Radiation is a non-thermal process which is used to remove poisons, microbes, and pests from food goods (Fernandes *et al*., 2012) [19]. It is believed to be a resource-efficient, safe, and ecologically beneficial way to preserve mushrooms (Fernandes *et al*. 2014) [21]. Furthermore, radiation globally maintains the nutritional value, flavor, color, and taste of mushrooms without causing any harm. But depending on the type of mushroom, the complementary preservation techniques used, the radiation dose, and the radiation source, radiation may have varying effects on the nutrients in mushrooms (Mami *et al*. 2014) [42]. Electron, gamma, and ultraviolet beams are a few examples of radiation sources. According to the World Health Organization (WHO), food products that have undergone radiation exposure testing up to 10 kGy are safe (Mami *et al*. 2014) [42]. Nonetheless, consumers continue to object to eating contaminated food.

### 5. Effects of climate change on mushroom post-harvest quality
Numerous mushroom species have shown ecological responses to climate change at different spatiotemporal scales (Gange *et al*. 2007; Kauserud *et al*. 2008) [24, 35]. According to Taye *et al*. (2016) [65], temperature and precipitation both have a significant impact on the phenology and yield of mushrooms. Climate affects mushroom productivity, which is further impacted by site and substrate quality interactions as well as the structure of forest stands (Boddy *et al*. 2014; de-Miguel *et al*. 2014; Tomao *et al*. 2017) [5, 69]. In wet temperate regions, recent temperature increases caused by climate change have shown greater yield and earlier emergence, while drier Mediterranean conditions have decreased mushroom output. This is because warm, humid conditions encourage fungal fruiting (Boddy *et al*. 2014) [5]. Many climate change models suggest that future circumstances would be hotter and less precipitation, which will increase the levels of drought stress and aridity in forest ecosystems. Therefore, it is expected that these modifications will significantly reduce the productivity of mushrooms (Agreda *et al*. 2015; Buentgen *et al*. 2015) [6]. During the postharvest period, mushrooms experience a number of quality degradations, including moisture loss, discoloration, texture changes, off flavor, and nutritional loss (Ding *et al*., 2016) [14]. The content of moisture in mushrooms steadily decreases during the postharvest phase, resulting in ongoing weight loss. Due to water transpiration and enzyme activity, postharvest mushrooms turn brown, which affects consumer purchasing decisions. A multitude of factors influence the quality of mushrooms once they are harvested. These attributes are divided into two categories: those that are internal to the mushrooms directly (such as respiration rate, water activity, and microbial activity) and those that are external to the storage environment (such as relative humidity and storage temperature). Phenolperoxidase (PPO) is thought to be the main cause of *Agaricus bisporus* postharvest discoloration rather than hydrogen peroxide because PPO is naturally present in trace amounts in mushrooms (Lei *et al*., 2018) [40]. Mushrooms have a limited shelf life and are susceptible to microbial contamination because of their rapid loss of firmness following harvest (Gao *et al*. 2014) [25]. Factors effecting mushroom post-harvest quality.




### 6. Challenges and hopes for the future with regard to mushrooms' nutritional value
In food science and technology, Postharvest preservation methods for edible mushrooms have been significantly improved by recent developments. These incorporate of coating, radiation, plasma treatment, air-conditioned storage, and low-temperature storage. It's vital to remember that different edible mushroom species have very distinct postharvest preservation needs and reactions, calling for more careful research and optimization. One of the most popular types of mushrooms to eat, shiitake mushrooms are high in nutrients and offer several health advantages. The consumption of these type of mushrooms has many hazards too. Shiitake mushrooms are also difficult to digest for those who are allergic to them. Some consumers have

food poisoning, skin rashes, and allergic responses when consuming (Thompson, 2022) [68]. The mushroom is among the fungus that generates the highest protein. They therefore have the capacity to ensure both a sustainable economy and adequate nourishment. Mushrooms contribute to meeting food scarcity demands by maintaining food production and security. According to earlier research, edible mushrooms' respiration rate can be slowed down by using the right treatment and packaging strategies, which can postpone aging and prolong their freshness. Furthermore, control over environmental parameters like humidity and storage temperature is essential to preservation technology. While freezing is thought to be one of the greatest ways to maintain the nutritional content of mushrooms while they are in storage, frozen foods have the potential to lose nutrients over time.

## 7. Conclusion

Because they contain a number of bioactive compounds which have a range of health advantages, incorporate the ability to minimize the level of cholesterol and fight cancer, one common vegetarian protein source is mushrooms. Because of their fast respiration rate and lack of a cuticle, which would prevent them from leaking water, mushrooms deteriorate at an extremely high rate. More water in the mushroom makes it more vulnerable to microbial infection. As a result, several techniques for preserving quality after harvest have been put into practice. Steeping preservation in conjunction with long-term storage is the finest post-harvest preservation method. To improve the quality of mushrooms after harvest, it should be encouraged to employ a range of preservation techniques that involve little capital or short processing durations. It is crucial to create agricultural policies for the production of mushrooms, especially in light of the current issues with food and nutritional security, as well as climate change. In order to maintain an environmentally friendly ecosystem which can meet the demands of the two i.e. todays and the next generations, this is imperative.

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