

## Drying of mushrooms: A review

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### Abstract

The consumption of edible mushrooms has increased throughout the world due to its high nutritive value, texture and flavour. Mushrooms are a valuable source of nutrients, bioactive compounds, and dietary fiber, making them a popular ingredient in both culinary and nutraceutical applications. Mushrooms, being highly perishable, require preservation techniques such as drying to extend their shelf life while maintaining their nutritional and medicinal properties. This review explores various drying methods used for mushrooms, including conventional hot air drying, freeze drying, vacuum drying, and microwave drying. Recent advancements in drying technology, such as the use of combined methods (e.g., microwave-assisted and vacuum drying), are highlighted for their potential to improve quality while reducing energy consumption. This comprehensive overview aims to provide insights into the selection of suitable drying techniques for mushrooms, contributing to improved product quality and sustainability in the mushroom processing industry.

**Keywords:** Mushrooms, drying methods, nutritive value, technology

### Introduction

The fruiting body of a fungus that is fleshy and bears spores is called as mushroom. Mushrooms can develop on dead and decomposing matter. Mushrooms belongs to the *Ascomycota* and *Basidiomycota* families, respectively (Oluwamodupe and Tesleem, 2012). All around the world, mushrooms are a vital part of diets and pharmaceutical goods because of their highly regarded nutritional and medicinal qualities. Interest in growing and subsequently consuming mushrooms as a food source has surged along with the global population. Since 1990, the mushroom industry has gained global attention, which has led to a sharp rise in production (Rosmiza *et al.*, 2016, Raut J. K. 2019). The production of mushroom in the world is 44 million tonnes and in India it is about 0.24 million tonnes (Anonymous, 2023). As per National Horticulture Board, Bihar is India's leading producer of mushrooms with production more than 28,000 tonnes (10.82%) of the total mushrooms produced in the country. Maharashtra ranks second (9.89%) of the total mushroom production throughout the country (Anonymous, 2023). The most cultivated mushrooms in the world are *Agaricus bisporus*, *Lentinula edodes*, *Pleurotus spp.*, *Auricularia auricula-judae*, *Volvariella volvacea*, and *Flammulina velutipes* (Valverde *et al.*, 2015). Mushrooms are of commercial importance due to their nutritional and medicinal value (Celen *et al.*, 2010)<sup>[2]</sup>. Since ancient times, people have utilised edible mushrooms as food. They are valued for their flavour and texture as well as certain nutritional and medicinal qualities (Manzi *et al.*, 2001). Mushrooms are also described as an excellent choice to include in low caloric diets since they have high amounts of dietary fiber, minerals, vitamins, water, protein, carbohydrates, and low content in lipids (Kalac, 2012). The mushrooms protein, carbohydrate, and lipid contents have been estimated between 13.8 g to 38.5 g, 32 g to 61.4 g, and 0.4 g to 5.9 g per 100 g, respectively (Dimopoulos *et al.*,

2022). Mushroom possess many nutraceutical properties such as prevention or treatment of parkinson, alzheimer, hypertension, and high risk of stroke, also mushrooms act as antibacterial, immune system enhancer and cholesterol lowering agents; additionally, they are important sources of bioactive compounds Valverde *et al.* (2015).

Fresh mushrooms must be consumed or processed quickly after being harvested since they have a soft texture and are highly perishable (Sahbaz *et al.*, 2000; Giri and Prasad, 2007). Mushrooms have 85–95% moisture content (Rahi and Malik 2016). Mushrooms undergo constant quality deterioration during the postharvest period, exhibiting discolouration, moisture loss, texture changes, an increase in the microbial count, and a loss of nutrients and flavour. Postharvest preservation methods are crucial for preserving the quality of mushrooms after harvest and extending their shelf life (Zhang *et al.*, 2018)<sup>[44]</sup>. By regulating storage temperature and water activity, thermal processes like drying and chilling are common methods that considerably reduce the degradation of mushroom quality (Pei *et al.*, 2014)<sup>[27]</sup>. Techniques such as modified atmosphere packaging (MAP), physical and chemical methods like irradiation, pulsed electric fields, antimicrobial washes, coating applications, and treatments with electrolyzed water (Zhang *et al.*, 2018)<sup>[44]</sup> could effectively inactivate microbial activity and impact physical properties, including texture, color, and weight loss.

Among the preservation methods mentioned above, drying is the most prevalent practice worldwide, attributable to its extensive theoretical, practical, and historic foundation, along with its cost-effectiveness and simplicity (Xue *et al.*, 2017)<sup>[41]</sup>. Drying makes it easier to handle, store and transport since it reduces mass (Lidhoo and Agrawal, 2008)<sup>[19]</sup>. Drying reduces the moisture content of mushrooms to below 10-12%, inhibiting microbial growth and enzymatic activity responsible for spoilage. This extends their shelf life by preventing deterioration and ensuring stability during

storage (Celen *et al.*, 2010) [2]. There are number of drying methods used for drying of mushrooms such as hot air drying (Kotwaliwale *et al.*, 2006; Doymaz, 2014; Mirzaei-Baktash *et al.*, 2022) [6, 17, 22], freeze drying (Wang *et al.*, 2015; Tarafdar *et al.*, 2017; Shams *et al.*, 2022) [30, 33, 38], vacuum drying (Walde *et al.*, 2005; Ucar and Karadag, 2019) [34, 35], microwave drying (Giri and Prasad, 2005; Ghaderi *et al.*, 2012; Das and Arora, 2018; Omari *et al.*, 2018) [4, 11, 13, 26], infrared drying (Darvishi *et al.*, 2013; Wang *et al.*, 2019) [3, 36], etc. Accordingly, the review focuses on different methods used in mushroom drying along with their advantages and disadvantages with optimum drying conditions.

### Different drying methods used for mushroom

Drying, also known as dehydration is one of the oldest and most traditional methods of preserving food. All drying methods operate on the fundamental principle of dehydrating materials through the simultaneous transfer of heat and mass (Dinani *et al.*, 2014) [5]. The various drying methods used for mushroom are presented in this review.

#### 1. Hot air drying

Hot air drying is a widely used method in food processing, where heat is transferred to a material through hot air, causing moisture to evaporate. The process involves two main mechanisms: heat transfer and mass transfer. Heat transfer occurs as hot air circulates over the material, raising its temperature and promoting the movement of moisture from the interior to the surface. The moisture then evaporates into the surrounding air. The efficiency of hot air drying is influenced by factors such as air temperature, airflow rate, and the material's thickness and surface area. Higher temperatures can speed up drying but may cause nutrient degradation, while adequate airflow is necessary to remove moisture-laden air and maintain the moisture gradient (Mechlouch *et al.*, 2015) [21]. Hot air drying is a cost-effective and simple method, but it can lead to uneven drying and potential quality loss if not carefully controlled (Sharma *et al.*, 2021) [31].

Hot air drying is a commonly used method for preserving mushrooms, offering both advantages and disadvantages. One of its main benefits is cost-effectiveness, as it is relatively affordable compared to more advanced techniques like freeze-drying (Nadew *et al.*, 2024) [23]. The process is also simple and does not require specialized equipment, making it accessible for large-scale operations and small producers alike (Sarkar *et al.*, 2020) [28]. However, hot air drying has several drawbacks. The high temperatures used can lead to significant nutrient degradation, particularly in heat-sensitive compounds such as vitamins and antioxidants, which reduces the nutritional value of the mushrooms (Wang *et al.*, 2014) [37]. Additionally, the process can cause mushrooms to become darker and harder, affecting both their texture and appearance (Khaled *et al.*, 2020) [16]. Hot air drying is also more time-consuming compared to other methods, such as microwave-vacuum drying, which can be a disadvantage in commercial settings (Zahoor *et al.*, 2023) [42]. Despite these limitations, hot air drying remains a popular method due to its simplicity and cost-efficiency.

#### 2. Freeze drying

Freeze drying also referred to as lyophilization or cryodesiccation, this process involves removing water from a product in the form of ice through sublimation under

extremely low pressure. The freeze-drying (FD) process generally consists of three stages: freezing, sublimation and desorption (Nowak and Jakubczyk, 2020) [25]. Freeze-drying (FD) is carried out at low temperatures to maintain the flavor, color, and overall quality of the food while protecting heat-sensitive nutrients from thermal damage (Fellows, 2017) [9].

Freeze-drying mushrooms offers several advantages, including better retention of nutrients, flavor, color, and bioactive compounds compared to other drying methods (Baggio *et al.*, 2012; Shofian *et al.*, 2011) [1, 32]. It also improves rehydration properties, extends shelf life, and preserves structural integrity, making it ideal for long-term storage and culinary use. Freeze-drying (FD) is an expensive technology characterized by high initial costs, significant energy consumption, and lengthy processing times. However, it offers several advantages over traditional drying methods in terms of product quality (Bhandari, 2012). Freeze-drying mushrooms has been shown to preserve their nutritional and sensory qualities effectively. Studies indicate that freeze-dried mushrooms retain higher levels of antioxidants, vitamins, and bioactive compounds compared to other drying methods, such as hot air or microwave drying (Baggio *et al.*, 2006). In terms of texture and flavor, freeze-drying minimizes shrinkage, retains the original color, and maintains a more desirable taste and aroma (Shofian *et al.*, 2011) [32]. Additionally, freeze-dried mushrooms exhibit superior rehydration properties, which is crucial for culinary applications. Research also highlights that the freeze-drying process extends the shelf life of mushrooms by preventing microbial growth and chemical degradation (Wang *et al.*, 2015) [38].

Freeze-drying mushrooms, while offering several advantages, also has notable disadvantages. One of the primary drawbacks is its high cost, both in terms of initial investment and energy consumption, making it less accessible for small-scale operations (Ibrahim *et al.*, 2023). The process is also time-consuming, requiring long drying periods, which can impact production efficiency (Dziki, 2020) [7]. Furthermore, freeze-drying can result in the loss of certain volatile compounds, affecting the flavor profile of mushrooms, although this is generally less severe compared to other drying methods (Wang *et al.*, 2021) [39]. Additionally, the equipment required for freeze-drying is complex and requires careful maintenance, adding to the overall operational costs (Wang *et al.*, 2014) [37]. These factors make freeze-drying less attractive for producers who prioritize cost-effectiveness and rapid processing.

#### 3. Vacuum drying

Vacuum drying is a technique that involves drying mushrooms under reduced pressure, typically below the vapour pressure of water. In this process, heat is applied to the mushrooms, causing the water inside them to evaporate. However, because the drying occurs in a vacuum environment, the boiling point of water is significantly lowered, allowing moisture to be removed at lower temperatures, which helps preserve the nutritional and sensory qualities of the mushrooms (Ucar *et al.*, 2019) [34]. The reduced pressure minimizes oxidation and prevents the degradation of heat-sensitive compounds, such as vitamins and antioxidants, making vacuum drying particularly suitable for preserving the bioactive compounds in mushrooms. Additionally, vacuum drying can offer faster

processing times compared to conventional hot air drying while retaining the texture and flavor of the mushrooms (Walde *et al.*, 2005) [35]. However, the high initial cost of equipment and energy consumption remain challenges for widespread use. Despite these drawbacks, vacuum drying is considered a valuable method for high-quality mushroom preservation.

Several studies have explored the use of vacuum drying for mushrooms, highlighting its advantages in preserving quality. Ucar *et al.* (2019) [34] noted that vacuum drying helps retain the nutritional content of mushrooms by operating at lower temperatures, thus minimizing the loss of heat-sensitive compounds. Walde *et al.* (2005) [35] investigated the effects of vacuum drying on the antioxidant activity and nutritional properties of mushrooms, finding that vacuum-dried mushrooms retained more antioxidants compared to those dried by conventional methods. Zecchi *et al.* (2011) [43] also compared vacuum drying to hot air drying, concluding that vacuum drying resulted in superior retention of texture and colour in mushrooms. However, despite its benefits, the high energy consumption and the cost of vacuum drying equipment are limiting factors, as noted by Kantrong *et al.* (2014) [15]. These studies demonstrate that vacuum drying is an effective method for preserving the quality of mushrooms, but its commercial feasibility depends on addressing the challenges of cost and energy use.

#### 4. Microwave drying

Microwave drying is an innovative method that uses microwave radiation to rapidly heat and remove moisture from mushrooms. This allows for faster drying times compared to conventional methods like hot air drying (Wang *et al.*, 2019) [36]. One of the key advantages of microwave drying is its ability to preserve the nutritional

content, flavor, and color of mushrooms due to the relatively low temperatures involved (Lenaerts *et al.*, 2018) [19]. The technique also results in less shrinkage and texture degradation, making the mushrooms more visually appealing and suitable for culinary use (Wang *et al.*, 2014) [37]. However, microwave drying has some disadvantages. One key issue is the uneven distribution of heat, which can lead to localized overheating or under-drying, resulting in poor quality or inconsistent drying of mushrooms (Kumar *et al.*, 2016) [18]. It requires precise control over microwave power and exposure time to avoid uneven drying and potential over-heating, which can lead to nutrient loss and textural changes. Additionally, the equipment used for microwave drying is more expensive than traditional drying methods, which may limit its adoption for smaller-scale operations (Elmizadeh *et al.*, 2017) [8]. Despite these challenges, microwave drying remains an efficient option for mushroom preservation, particularly when quality retention is a priority.

Previous studies on microwave drying of mushrooms have highlighted its advantages in terms of speed, nutrient retention, and quality preservation, as well as some challenges. Zhang *et al.* (2018) [44] compared microwave drying with conventional methods and found that microwave drying significantly reduced the drying time of mushrooms while maintaining better colour and flavour. Similarly, Seremet *et al.* (2016) [29] investigated the effect of microwave drying on the texture and nutritional properties of mushrooms and concluded that this method helped retain antioxidants, vitamins, and overall nutritional value better than hot air drying. Wang *et al.* (2019) [36] explored the impact of microwave drying on the antioxidant capacity of mushrooms, revealing that the rapid heating preserved bioactive compounds more effectively compared to traditional drying techniques.

**Table 1:** Various drying methods for mushrooms

Sr. No.	Mushroom variety	Drying method	Drying parameters and results	Reference
1.	Agaricus bisporous	Hot air drying	Drying temperature: 65°C. Reduced the drying time and energy consumption and also improved drying rate and effective moisture diffusivity	Mirzaei-Baktash <i>et al.</i> , 2022 [22]
2.	Agaricus bisporous	Hot air drying	Drying temperature: 40, 50, 60, and 70°C. Temperature had significant effect on the moisture removal.	Doymaz, 2014 [6]
3.	Agaricus bisporous	Microwave- vacuum drying	microwave powers: 130, 260, 380 and 450W and absolute pressures 200, 400, 600 and 800 mbar	Ghadari <i>et al.</i> , 2012 [11]
4.	Lentinula edodes	Combined Mid-infrared drying and freeze-drying	Shorten the drying time	Wang <i>et al.</i> , 2015 [38]
5.	Agaricus bisporous	Hot air drying	Slice thickness 3 and 5 mm, drying temperatures 40, 50 and 60 °C and air flow rates of 1 and 1.5 m s <sup>-1</sup> . Drying rate was increased with decreasing thickness and increasing temperature and velocity.	Ghanbarian <i>et al.</i> , 2016 [12]
6.	Lentinula edodes	Hot air drying (HD) and freeze drying (FD)	Drying temperatures 50, 60 and 70 °C, total free amino acids in HD samples treated at 60°C was the highest	Yang <i>et al.</i> , 2019
7.	Agaricus bisporous	Alternate microwave (MW) and hot air drying	The optimal time of MW application was found 20 ± 3 min based on minimum drying time and better-quality attributes.	Das and Arora., 2018 [4]
8.	Agaricus bisporous	Microwave-hot air drying	Temperature 23, 50, and 70 °C three levels of microwave power density (MPD): 1.5, 2, and 2.5W/g. The lowest specific energy consumption was found in 23°C and 2.5 fixed MPD and lowest colour deterioration found in 70°C and 1.5 fixed MPD.	Omari <i>et al.</i> , 2018 [26]
9.	Paddy straw mushroom ( <i>Pleurotus</i> spp.)	Hot air drying	Drying temperature: 50, 55, 60, and 70 °C. High temperature drying caused hardness in dried mushrooms while cohesiveness decreased. Drying temperature had an inverse effect on whiteness of mushrooms.	Kotwaliwale <i>et al.</i> , 2006 [17]
10.	Agaricus bisporous	Freeze drying	Pressure (0.04, 0.07, and 0.10 mbar), primary drying temperature (-2, -5, and -8 °C), and secondary drying temperature (25, 28, and 31°C)	Tarafdar <i>et al.</i> , 2017 [33]

## Conclusion

The review highlights that different drying techniques for mushrooms significantly impact their quality attributes, including nutritional value, texture, color, and flavour. Among the methods, hot air drying is cost-effective and widely used but often results in notable nutrient loss and shrinkage. Freeze drying excels in preserving the nutritional and sensory qualities of mushrooms, though its high operational costs and longer drying times limit its broader application. Vacuum drying strikes a balance by offering better retention of bioactive compounds compared to hot air drying, but it still involves higher costs and complexity. Microwave drying, on the other hand, provides rapid drying with better energy efficiency and good retention of some nutrients, but it can lead to uneven drying and textural changes if not carefully optimized. Overall, the choice of drying method should align with the desired product quality, economic feasibility, and specific application needs, making it essential to consider these trade-offs when selecting the most suitable drying approach for mushrooms.

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