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Dehydration and Quality of Dried Mushrooms: A Review

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ABSTRACT

The production of mushrooms is increasing at a rapid pace due to advanced production technologies and higher consumption throughout the world. The consumption of edible mushrooms has increased throughout the world due to its high nutritive value, texture and flavor. Mushroom cultivation in India is emerging as secondary agricultural based land independent enterprises with huge local and export market potential. The post harvest life of mushrooms is very limited due to high moisture content and water activity, microbial, enzymatic activity and biochemical reactions. Storage of fresh mushrooms is a major problem in Indian conditions due to the lack of a cold chain system in India. Preservation of mushroom is very essential for reducing post harvest loss and extending shelf life whilst maintaining nutritional and organoleptic qualities for consumer's acceptance and availability of products during off-season. Dehydration is the most popular and important technique to increase the shelf life of mushrooms by reducing moisture content up to a level at which undesirable charges are prevented. The drying techniques which have the great potential for the production of quality dried mushrooms and powders are solar drying, tray drying, vacuum drying, microwave-vacuum drying, freeze drying and heat pump drying. Pretreatment before drying seems to be an effective method of preservation of mushrooms with minimum changes in nutritional and sensory quality to increase consumer's acceptability and market potential of dehydrated mushrooms. This review gives the information on pretreatments, dehydration and quality of dehydrate mushrooms.

KEYWORDS: Dehydration, mushrooms, preservation, pretreatment, shelf life and quality

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1. INTRODUCTION

Mushrooms are edible fungi of commercial importance due to their high nutritional value, delicacy and flavor. Fresh mushrooms contain about 85–90% moisture content, 3% protein, 4% carbohydrate, 0.3–0.4% fat and 1% minerals and vitamins. It represents an excellent source of protein, vitamins (B_1, B_2, niacin, C, folic acid, and provitamin D ergosterol), dietary fibers, minerals (P, K, Na, Ca, and Fe) and is low in fat (Farzana et al., 2016). On dry matter basis, protein content in mushrooms ranges from 20% to 40% and contain an abundance of essential amino acids like lysine and leucine which are limited in cereal grains (Farzana et al., 2016). Mushroom protein is superior to other plant proteins in terms of essential amino acids contents for human growth & health and digestibility (Jiskani, 2001 and Manzi et al., 2001). The production of mushrooms is increasing at a rapid pace due to advanced production technologies and higher consumption throughout the world. Mushroom cultivation in India is emerging as promising agro-based, land independent enterprises with huge export potential (Gothandapani et al., 1997). The most prominent edible varieties of mushroom are button mushroom (*Agaricus bisporus*), oyster mushroom (*Pleurotus* spp.) followed by milky mushroom (*Calocybe indica*). Mushroom industry in India is mainly focused on button mushroom production and marketing. India stands at 6th position in production of mushrooms with around 2,80,000 mt (Anonymous, 2022). The button mushroom production holds the maximum share of about 70%, oyster mushroom with 17% share, paddy straw mushroom with 9% share and milky mushroom with 3% share (Bijla and Sharma, 2023). The white button mushroom is the most popular among the cultivated mushrooms and ranks first at the global level (Gupta et al., 2018).

Whole mushrooms have a short postharvest life compared to most vegetables due to high respiration rate and water content, making them prone to microbial spoilage and enzymatic browning (Brennan et al., 2000). Mushrooms are highly perishable and start deteriorating immediately within a day after harvest and hence have limited shelf life (Raj et al., 2013). The development of brown colour is the first sign of deterioration due to enzymatic action of polyphenol oxidase on phenolic substances and is a major factor contributing to quality losses. Microbial, enzymatic and chemical reaction, discoloration, colour and flavour changes and textural changes are the factors which lower its quality and thus reduce the consumer's acceptance for fresh mushrooms. Therefore, the preservation of mushroom to make shelf stable at room temperature is very essential and it is the necessity and concern of the mushroom growers and processors, which can only be accomplished through suitable processing and preservation techniques. Dehydration is the oldest method of food preservation to extend shelf life of mushrooms as removal of available moisture prevents the growth and reproduction of micro-organism causing decay and minimizes many moisture mediated deteriorative reactions (Cohen and Yang, 1995) which could change their quality. It also improves appearance, maintains the original flavor & nutritional quality, brings about substantial reduction in weight and volume, reduces packaging cost & transportation cost and enables storability of product under ambient temperature (Chou and Chua, 2001). The various techniques for preservation of mushrooms are freezing, canning, drying, steeping, etc. Among these techniques, drying is an effective method and relatively inexpensive method for prolonging the shelf life of fresh mushrooms (Jiang et al., 2016). Selection of appropriate dehydration techniques is very critical to maintain quality of the mushroom. Some of the important novel methods of dehydration include heat pump drying, vacuum drying, freeze drying, radiant energy vacuum dehydration, microwave-vacuum drying, osmotic dehydration and modified atmosphere drying. These methods give good quality dehydrated products and have ample potential to get maximum benefit and the products can be exported in world market.

Dehydrated mushrooms are used as an important ingredient in several food formulations including instant soups, pasta salads, health drinks, cake, bakery products, snack seasonings, stuffing, casseroles, and meat and rice dishes (Farzana et al., 2016). The dehydrated mushroom packed in airtight containers can have a shelf life of above one year with desired quality (Bano et al., 1992). The blanching pretreatments before dehydration are effective methods of shelf-life extension of mushrooms with consumer's acceptability as enzymes are inactivated and visual color, odour, aroma etc. are retained. This review paper presents the pretreatments of mushrooms, dehydration of mushrooms and quality of dehydrated mushrooms.

2. PRETREATMENTS OF MUSHROOMS

The rate of respiration in freshly harvested mushrooms is high in comparison to other horticultural crops due to which mushrooms have limited shelf life under ambient temperature. Mushrooms develop brown colour due to the enzymatic reaction of phenol oxidase and become quickly soft at a high ambient temperature. Blanching is a pretreatment which is normally carried out before dehydration, freezing, frying and canning of mushrooms to get higher quality finished product by inactivating polyphenol oxidase (PPO). One of the main objectives of blanching of some of the fruits and vegetables is to inactivate the enzymes to avoid undesirable changes in sensory characteristics and nutritional qualities during storage. Physical or chemical pretreatment of fruits and vegetables before drying reduces the drying time, energy consumption and preserve the quality of products (Yu et al., 2017). It is an essential step before dehydration of mushroom to prevent undesirable changes during processing & storage and maintain desirable quality attributes for consumer's acceptance (Raj et al., 2012). It is used to inactivate the enzymes that cause off-flavor and odor, retain fresh like color, texture stability, and nutritional quality, expel air trapped inside plant tissues and reduce microbial load (Xiao et al., 2017). The effectiveness of the blanching process depends on the type of fruit or vegetable, size of fruit or vegetable, method of heating, time and temperature of blanching. The optimum time and temperature combination with a suitable heating medium is required for proper blanching of mushroom followed by cooling to get uniform and attractive color of dehydrated mushroom and its powder. There are various techniques of blanching such as hot water blanching, steam blanching, microwave blanching, fluidized bed blanching, hot gas blanching, etc. Hot water blanching and steam blanching are generally used for vegetables (Lal et al., 1998). The hot water and steam are the most widely used heating media for blanching.

Hot water blanching is still the most common and commercially adopted blanching process, because of its ease of use, simplicity of equipment, and low investment. The blanching pretreatment improves the drying behavior of fruits and vegetables by reducing drying time and increasing drying rate (Falade and Solademi, 2010). Typical commercial blanching process is carried out at 90–95°C for 1–10 min followed by a rapid cooling process (Puupponen-Pimia et al., 2003). In vegetable systems, peroxidase (POD) is considered the most thermally resistant enzyme that may catalyze undesirable reactions leading to browning. Therefore, inactivation of POD can be used as a reference to determine important parameters of the blanching process (Pellicer and Gómez-López, 2017). Several researchers have studied and reported the optimum conditions for blanching of vegetables (Von-Loeseede, 1955, Kalra, 1990). Deshpande and Tamhane (1981) reported that water blanching for 3 min was sufficient to inactivate the PPO enzyme which causes browning during drying of the mushroom. There are several chemical additives, which are added in small quantities in food to improve the appearance, flavour, texture and storage properties. The chemical preservatives were found to be advantageous in maintaining the nutritional quality, enhancing the keeping quality and making vegetable products attractive (Desrosier, 1970). These preservatives are potassium metabisulphite (KMS), sodium benzoate, citric acid, calcium and sodium chloride. The number of additives used in vegetables should be minimum and necessary to produce the desired effect (Lal et al., 1998). The recommended steeping preservation also inactivates the enzymes and further helps in keeping quality during storage. Sodium sulfite and sodium metabisulfite are frequently added to the blanching water to maintain the color of the product and inactivate microbiological activity. Mushrooms are usually blanched in water) or in aquatic solutions of antioxidative substances at 95–98 C for a period ranging from 20 s to 15 min (Bernas et al., 2006, Anonymous, 1995). Blanching preserves the color, lowers the microbial load, preserves vitamins and increases the drying rate (Von-Loesecke, 2001).

Steeping of water blanched mushroom in 1% KMC along with 0.2% citric acid (overnight) before drying improved colour, texture and rehydration properties (Pruthi et al., 1978). Rama and John (2000) reported that mushrooms dried after blanching with citric acid (0.3%) plus salt solution (2%) and steeped in KMS (1500 ppm SO_2) plus citric acid (0.1%) solution for 30 min showed the best colour. Chandra and Samsher (2002) immersed oyster mushrooms in boiling water at 100°C for 4 min and cooled immediately in cold water at room temperature and drained. The extent of heat treatment, time and equipment used for blanching vary from vegetable to vegetable and are also dependent on many variables. Arora et al. (2003) blanched both button and oyster mushroom in boiling water for 1 min and treated in solution containing 0.1% citric acid and 0.25% KMS for 15 min at room temperature resulting in lowest browning index. Arumuganathan et al. (2004) pre-treated with 0.05% KMS+0.1% citric acid followed by sun drying and found good quality dried mushrooms. Two-to-five-minute blanching in boiling water was reported to inactivate polyphenol oxidase (Fang et al., 1971, Deshpande and Tamhane, 1981, Mudahar and Bains, 1982, Suguna et al., 1995). Rama and John (2000) reported that oyster mushrooms could be blanched in boiling water for 3–4 min. Singh et al. (2001) used various pretreatments for button mushrooms such as blanching, soaking in 0.5% KMS; soaking in 1% KMS, 0.2% citric acid, 6% sugar and 3% salt solution prior to dehydration and reported that samples dried at 50°C gave satisfactory results.

3. DEHYDRATION OF MUSHROOMS

Dehydration or drying is one of the most common preservation methods for extending the shelf life of food materials by reducing the water content to prevent the growth & reproduction of microorganisms and many of the moisture-mediated deteriorative reactions (Mujumdar, 2014). Drying has been used as a method of reducing post-harvest losses in many agricultural produce for a long time (Gatea, 2011) and as well as improving commercial value. Drying of food materials refers to the removal of moisture to a predetermined level and is governed by heat and mass transfer laws (Sahay and Singh, 2001). It reduces the weight and volume of food materials and minimizes packaging, storage, and transportation costs and enhances keeping quality (Kamiloglu et al., 2016). The dehydrated product offers, apart from increased shelf life and pleasant flavor, the advantages of decreased mass and volume, which have the potential for savings in the cost of packaging, handling, storage and transport of the product (Karimi, 2010). Mushrooms are highly perishable in nature because of its high moisture content & nutritional quality; hence it starts deteriorating within a day after harvest. The shelf life of mushrooms is also very limited due to its high respiration rate, water activity and enzymatic activity. The storage of mushrooms under ambient conditions is a great problem. Drying is an effective method for prolonging the shelf life of fresh mushrooms (Jiang et al., 2016). There are several methods of drying which are used for dehydration of vegetables/mushrooms. These methods include sun-drying, solar drying, hot air drying, fluidized bed drying, vacuum drying, microwave drying, freeze drying, and heat pump drying (Cruess, 1946, Desrosier, 1970, Pruthi et al., 1978, Deshpande and Tamhane, 1981, Mudahar and Bains, 1982; Nehru et al., 1995, Singh et al., 1995, Suguna et al., 1995, Rama and John, 2000, Singh et al., 2001, Chandra and Samsher, 2002; Gaurh et al., 2017). The combination of these drying methods are also for dehydration of mushrooms. The general procedure recommended for mushroom drying includes washing, slicing, blanching, drying, packaging and storage (Kaushal and Sharma, 1995). The energy consumption and quality of dried products are critical parameters in the selection of drying process. An optimum drying system for the preparation of quality dehydrated products should be cost effective as it shortens the drying time and cause minimum damage to the product. The final product quality is very important in respect to processing cost, nutritional and sensory attributes like taste, flavor, texture, colour, etc. The preservation by drying is very useful under Indian conditions.

4. SUN DRYING

Sun drying is a very simple method in which no fuel or mechanical energy is required. It is the most popular method among farmers for drying due to its simplicity and cheapness (Sontakke and Salve, 2015) in which solar energy is utilized. It is a slow process, labour intensive, unhygienic, time consuming and losses due to birds, rodents and insects are more. Sun dried product contains more than 10–12% moisture content and therefore it should be oven dried at 55–60°C for 4–6 h further to reduce the moisture content up to 7–8% to avoid any spoilage during storage. Rama and John (2000) reported that when the temperature during sun-drying ranged from 21.6–35.7°C, time taken was 14 h for the pretreated oyster mushroom and 12 h for the untreated oyster mushroom to reach 5–6% moisture level. They also reported that the dehydration ratio, shrinkage ratio and rehydration ratio of the sun dried product were 10.64, 0.19 and 2.21 respectively. The colour of the final product varied from brown to creamy white. Suguna et al. (1995) dried oyster mushrooms in the open sun and reported that sun drying took 8 to 9 h to reach the required final moisture content. Chandra and Samsher (2002) dried oyster mushrooms in the open sun and they reported that drying took 720–744 min at ambient temperature 12–30°C. Arumuganathan et al. (2004) conducted the experiments on sun drying of oyster mushrooms and found that the treatment with 0.05% KMS+0.1% citric acid yielded good quality dried oyster mushrooms. Suguna et al. (1995) carried out experiments on oyster mushrooms using sun drying with other drying methods. It was reported that sun drying took 8 to 9 h to reach the required final moisture content. Chandra and Samsher (2002) reported that oyster mushroom was sun dried which took 720–744 min depending upon pretreatments. The ambient temperature during the drying period was 12–30°C.

5. SOLAR DRYING

The process of drying in which solar energy is utilized for drying food materials utilizing the principle of greenhouse effect is called solar drying. The device which is used for drying food materials using solar energy is called a solar dryer. With the rising costs of conventional fuels and increasing awareness of the dangers of pollution, solar dryers are becoming a technically and economically viable option in many industrial and agricultural applications**.** A solar dryer is another application of solar energy, used immensely in the food and agriculture industry. Solar drying uses hot air convection principle to naturally release moisture. The optimal temperature for drying oyster mushrooms was 65°C in a solar dryer which improved the quality of dried oyster mushrooms (Sukkanta et al., 2023). Chandra and Samsher (2002) reported that the inside temperature of the polyhouse varied from 20–50°C during the day-time against the ambient temperature of 12–30°C in the winter season and total dehydration time varied from 540 to 660 min. The quality of mushroom dried under the poly house was better than sun and vacuum drying except tray drying. Nehru et al. (1995) designed and developed a solar drier and dried oyster mushroom with a capacity of 2.5 kg day^{-1}. Suguna et al. (1995) dried oyster mushroom in natural convection solar cabinet dryer and it took a drying time of 7 h when the ambient temperature varied between 29 and 32°C. Rama and John (2000) reported the final moisture content of 5–6% (w. b.) of oyster mushrooms which dried in 14 h. Nehru et al. (1995) dried oyster mushrooms in a solar dryer and reduced moisture content from 92.6% to 10% (w. b.) in 5.5 h to 6.5 h. Solar dryers have the potential for adoption and application in India. Mushrooms produced by this method have better quality with higher hygienic conditions and brighter color compared to the sun-dried mushrooms. Therefore, the dried mushrooms should be put into polyethylene bags, sealed and kept in a dry, cool and dark place. Hence, it can be concluded that a solar dryer is a viable alternative for drying mushrooms with quality attributes.

6. HOT AIR DRYING

Hot air drying is one of the most widely investigated and reported techniques. A large number of researchers have studied the effect of temperature in the range of 45–105°C, air velocity (0.5–2.0 m s^{-1}), slice thickness (10.0–12.5 mm), grading into large, medium and small, tray loading of 6.0–7.0 kg m^{-2} and pretreatments on dehydrated mushroom quality measured in terms of appearance, colour, flavour, texture, volume shrinkage, rehydration ratio, rehydration time and nutritive values and also on drying rate drying time^{-1}, drying characteristics and drying rate constant (Mlodecki et al., 1973, Zhuk and Tsapalova, 1973, Chen and Chen, 1981, Cho et al., 1981, Back et al., 1989, Bano et al., 1992, Suguna et al., 1995). Lidhoo and Agrawal, (2006) reported that button mushroom slices were dried at 45,55,65,75, 85 and 95°C in a hot air oven and it was observed that the minimum browning index was recorded at 65°C and the rehydration ratio obtained at this temperature was 2.9. Moisture content in mushroom slices during hot-air drying at 65°C decreased exponentially with time reaching storage moisture in 6 h. Mudahar and Bains, (1982) used hot air to dry mushrooms and reported that temperature of 55°C is suitable to obtain the end product with the desired qualities of texture, colour and rehydration. Rama and John, (2000) studied the mechanical drying of oyster mushrooms. They maintained the temperature at 60°C for the first 4 h and later at 50°C for the rest of 11 h of drying to reach a moisture content of 5–6% except the samples without any pretreatment which took only 8 h. They found dehydration ratio, shrinkage ratio and rehydration ratio of 9.89, 0.2 and 2.61 respectively.

Singh et al. (2007) studied dehydration characteristics and quality analysis of button mushroom slices thickness of 05, 0.7 and 0.9 mm at the air temperature of 40, 45, 50 and 55°C. Quality of dehydrated slices were evaluated on the basis of colour and amino acid content. The samples dehydrated at 50°C showed better quality. Pandey et al. (2002) dried milky mushrooms in a hot air oven and observed that the rehydration ratio of hot air oven-dried products was better than sun dried samples. Lidhoo and Agrawal (2006) dried white button mushrooms in a hot air oven dryer and found a minimum browning index at 65°C and a rehydration ratio of 2.9. Rama and John (2000) dried oyster mushrooms in a mechanical dryer and found the drying time of 4 h at 60°C and drying time of 11 h at 50°C to the final moisture content of 5–6% except the samples without any pretreatment which took only 8 h. They reported dehydration ratio, shrinkage ratio and rehydration ratio of 9.89, 0.2 and 2.61 respectively. Qin et al. (2020) dried mushrooms in a hot-air dryer at 60°C within 12 h and reported the sensory and volatile profile changed significantly during the drying process. Mihalcea et al. (2016) dried brown mushrooms and white mushrooms slices using a tray dryer at different temperatures of 50, 60 and 70°C respectively. They reported that the total color parameter (ΔE), the values of L and a were significantly ($p<0.05$) influenced by the drying temperatures. The total color changes (ΔE) were higher, while the L values were lower in the brown mushrooms samples than in white mushrooms.

7. FLUIDIZED BED DRYING

Fluidized bed drying technique is used to remove the moisture from the agricultural produce. The hot fluidizing medium absorbs moisture from the solid materials and as it rises through the bed allows products to mix well and good heat and mass transfer between food materials and drying medium. This method gives high-quality dried food materials (Moreira, 2011). Singh et al. (2001) reported the effect of drying air temperature and standard pretreatments on the quality of mushrooms dried in fluidized bed dryers. White button mushroom samples were dehydrated at five levels of drying air temperature (50, 60, 70, 80, and 90°C) with 3.2 m s^{-1} air velocity in a fluidized bed dryer. The samples were dried upto equilibrium moisture content at atmospheric pressure and took approximately 7, 6, 5, 4, and 3 h at 50, 60, 70, 80, and 90°C, respectively. Suguna et al. (1995) used a fluidized bed dryer and solar cabinet dryer for drying of oyster mushrooms. They designed and fabricated a batch type fluidized bed dryer of capacity 6 kg $batch^{-1}$. The optimum temperature was 50°C with an air flow rate of 35 m min^{-1}. The temperature inside the solar cabinet dryer varied from 45 to 60°C, while ambient temperature ranged from 29 to 32°C. Mushroom samples took 7 h to reach the final moisture content of 10% (w.b.). Singh et al. (1996) conducted the experiments on dehydration and steeping preservation of paddy straw mushrooms and reported the optimum drying temperature, time and critical moisture content of 60°C, 7 h and 5% (w.b.), respectively. They also reported that at 60°C temperature and 3–4 m/s air velocity, mushroom samples took 7 h to attain the final moisture content of 5% (w. b.). Deshpande and Tamhane (1981) dried paddy straw mushroom at 80°C in 7 kg batches in a fluidized bed dryer and reported that the product was acceptable upto two months when stored at 25˚C and 60% RH. Suguna et al. (1995) reported that oyster mushrooms dried in a fluidized bed dryer at 50˚C in 2 h in 6 kg batch and obtained a shelf life of five months.

8. MICROWAVE DRYING

Microwave drying involves the electromagnetic wave for drying food products in which waves penetrate food products due to moisture heats the products without creating thermal gradients and thereby dehydration process occurs (Jiang et al., 2010). For food applications, the common frequencies used are 915 and 2,450 MHz that permit the development of food products whilst maintaining food quality. Microwave drying of mushrooms at low power density in combination with heated air resulted in improved moisture diffusivity, better rehydration properties and improved favour retention (Riva et al., 1991). During microwave heating, the materials absorb microwave energy and convert it into heat by dielectric heating caused by molecular dipole rotation and agitation of charged ions within a high frequency alternating electric field (Spigno, 2016),

Kumar and Barmanray (2007) conducted three drying techniques for drying button mushroom slices such as sun drying, mechanical drying and microwave drying and they reported 90 minutes drying time to reach 6–8% of moisture content in microwave drying. Microwave dried samples were better in quality than sun dried samples. Giri and Prashad (2013) dried button mushrooms in a microwave-vacuum dryer. They reported significantly higher rehydration potential, lower density, better colour and softer texture than those obtained by air drying. The microwave-vacuum dried mushrooms were rated much better than air dried products by a sensory panel in terms of appearance, color and overall acceptability. Izli and Isik (2014) dried mushrooms in different drying methods such as microwave, convective and microwave-convective. The shortest drying time (35 min) was reported with the microwave method at 500 W. However, the drying time was significantly reduced by combining microwave treatment with conventional drying. The colour values of the samples dried at 50 ˚C were closest to the fresh samples for all drying conditions. Atalay and Erge (2021) dried white button mushroom in a microwave dryer and advocated that microwave drying is a suitable method for drying of mushroom slices within a shorter time compared with hot-air drying. The quality of dried mushrooms depends on the drying method and operating conditions. High initial cost, loss of aroma, degradation of texture are some of the disadvantages of microwave drying. Combination drying with an initial conventional drying process followed by a finish microwave or microwave vacuum process has proven to reduce drying time while improving product quality and minimizing energy requirements (Erle, 2005).

9. OSMO-CONVECTIVE DRYING

Osmo-convective drying technique involves the using of hypertonic solution and concentration gradient between moist foods products. This concentration gradient helps in drying and removal of water from plant tissues (Ishfaq et al., 2016). Main principle involved in osmotic dehydration is removing moisture at lower temperatures avoiding thermal treatments to get a product with colour, flavour and textural qualities nearest to the natural one (Amuthan et al., 1999). Osmotic dehydration can be used as an effective method to remove water from vegetable tissue while simultaneously introducing solutes in the product. The residue of the solute inside the product not only influences the taste and flavours of the product but as well the dielectric properties. Thus, halved mushrooms were osmotically pretreated with a sodium chloride solution (10% and 15% w/w, processing times are 10, 30, 50, 70 and 110 minutes, constant bath temperature of 20ºC and 45ºC) and subsequently dried by application of combined microwave/hot air heating and resulted more homogenous heating, short drying time, improved rehydration properties, reduce shrinkage and higher open pore porosity as an effect of pretreatment (Torringa et al., 2001). Dehkordi (2010) studied simultaneous effects of temperature, immersion time, salt concentration, sucrose concentration, pressure and osmo-convective drying on edible button mushrooms using response surface methodology. They reported that water loss, solid gain, rehydration ratio and shrinkage were 63.38 (g 100 g^{-1} initial sample), 3.17 (g 100 g^{-1} initial sample), 2.26 and 7.15%, respectively under optimum conditions. Torringa et al. (2001) gave the osmotic treatment of mushrooms with salt solution concentration (10–20% w/w) at 45˚C. The removal moisture was 30% of the total available moisture and the salt gain was up to 0.5 g salt g^{-1}. Shukla and Singh (2007) dried the mushroom at appropriate concentrated solution of sugar-salt, salt and sugar-salt plus $MgHCO_3$ in water and observed the reduction of moisture content during osmotic dehydration process in 5 h was 40–60% (w. b.). Further, the tray drying at 60 ˚C temperature was carried out to reduce moisture content of 6-8% (w.b.). Yang and Le (1992) conducted osmotic dehydration of button mushrooms in a continuously circulated contacting reactor and recommended 15% of salt solution for optimum removal of water. Pretreatments of the mushrooms in high concentrations of sucrose, followed by high salt concentration was the most effective method to remove water. Kar and Gupta (2001) reported that 15% brine solution removed about 35% of initial moisture in one hour. Amuthan et al. (1999) conducted the osmo-air drying of milky mushroom (*Calocybe indica*) and they observed that the moisture removal was higher by osmosis at 25% concentration of salt in 6 h duration. The colour of the osmo-air dried sample was very good as compared to the cabinet drying. Stavropoulou et al. (2022) conducted osmotic dehydration (OD) of button mushrooms at 50°C for 120 min, with a 42% glycerol solution and reported that OD-treated samples retained better quality attributes as compared to their untreated button mushroom. However, the osmotic drying process is economical and depends on: temperature of osmotic solution, concentration of the osmotic solution, osmotic agent used, process duration and geometry of food material.

10. VACUUM DRYING

During vacuum drying, high energy water molecules rapidly diffuse to the surface and evaporate into the vacuum chamber. The vacuum in the drying chamber reduces water vapor concentration at the surface of the products. In addition, it lowers the boiling point of water in the interior of the products. These create large vapour pressure gradients between the food interior and surface, resulting in significantly rapid drying rates. Thus, for a given rate of drying, vacuum enables the products to be dried at a lower product temperature than that under atmospheric pressure. Moreover, the absence of air during dehydration reduces oxidation. Because of these advantages, the colour texture, and flavour of dried products are all improved (Gunasekaran, 1999). Li-Shing-Tat and Jelen (1987) carried out vacuum drying of oyster mushrooms and compared the quality of dried mushrooms with air and freeze dried products. They found that the air dried mushrooms were shrunken and darker and had low rehydration capacity while the vacuum dried product had a similar appearance and rehydration ratio as freeze dried product. They also advocated its potential for mushroom drying due to its lower processing cost than freeze drying. Bano et al. (1992) dried mushrooms in a vacuum dryer and found a better product than air drying.

11. FREEZE DRYING

Removal of water from an agricultural produce by sublimation from the frozen state to the vapour state is known as freeze drying. Freeze drying seems to be better preservation method over other dehydration methods such as air or drum drying (Chin-Lin et al., 2003). Freeze-drying takes place in three stages; water present in the product is removed by formation of ice crystals; the ice crystals are then removed from the outer surface of the material by sublimation; after removal of all the ice, the little quantity of water left is then removed by evaporation in the freeze dryer. In a freeze-drying system, original shape and size can be retained and the shrinkage, which is a problem with other drying methods, is almost negligible. Freeze drying is frequently applied to materials that are prone to heat damage and produces products with excellent structural characteristics. Saxena and Rai (1990) dried mushrooms with freeze drying technique and reported that the appearance of dried mushrooms was very similar to fresh mushrooms. They packed the dried mushrooms in sturdy packings and cushion-packs flushed with nitrogen for better keeping quality and stored upto 6 months without any change in its quality and appearance. However, this method is a very costly and energy intensive process and the venture depends upon the demand and price for such products. Kannaiyan and Ramsamy (1980) dried mushrooms to a moisture content of 3% in a freeze drier and packed under vacuum. They obtained the best dehydrated mushroom product in terms of colour, flavour retention, texture, nutrient retention, and rehydration characteristics. The shelf life of freeze-dried product was 9–12 months when packed in hermetically sealed packages. Latpate et al. (2022) dried the button mushrooms in a freeze dryer at -20°C for 3 h and then dried in a tray dryer at 70–85°C for 6 h. The product had a rehydration ratio of 6.6 and sensory score of 7.4 and 6.8 for colour and overall acceptability respectively.

12. HEAT PUMP DRYING (HPD)

Heat pump drying of mushrooms involves using a heat pump system to remove moisture from mushrooms. This method is efficient and preserves the quality of mushrooms better than traditional drying methods because it allows precise control of temperature and humidity levels during the drying process and used for drying of highly valued heat sensitive materials. Heat pumps can recycle energy and maintain lower drying temperatures, which helps to retain the flavor, color, and nutrients of the mushrooms. This technique is gaining popularity due to its energy efficiency and ability to produce high-quality dried mushrooms suitable for various culinary and commercial applications. The HPD system is used at relatively low drying air temperatures (25–45 °C) whose operation is independent of ambient conditions (Minea, 2013). It is used in food industries due to its low energy consumption, minimum quality loss, high thermal efficiency, high drying performance, better control of the drying conditions and is environmentally friendly (Chou and Chua, 2001; Fatouh et al., 2006, Salehi, 2021). Heat pump drying is vastly used in food industries because less energy consumption, quality losses of foods are minimum, high thermal efficiency, better control of the drying conditions and is eco-friendly (Chou and Chua, 2001, Fatouh et al., 2006, Salehi, 2021). Due to the energy efficient and low drying temperature the structural damage, nutrients, flavours, natural colour and vitamins losses are minimal (Adapa et al., 2002, Pal and Khan, 2008). Juan et al. (2013) dried 90 kg fresh mushroom in 670 min and reported 33.2 kWh of electricity consumption. Sevik et al. (2013) dried mushrooms at 45°C and 55°C from initial moisture content of 13.24 g water g^{-1} dry matter (dry basis) to final moisture content of 0.07 g water g^{-1} dry matter (dry basis). They reported that the coefficients of performance of system (COP), energy utilization ratios (EURs) and Specific moisture extraction rate (SMER) were found to vary in the range of 2.1 to 3.1, 0.42 to 0.66 and 0.26 to 0.92 kg kWh^{-1} respectively.

Funebo and Ohlsson (1998) used hybrid microwave HPD for apple and mushroom and reported reduction in drying time. Fresh mushrooms having initial moisture content of 91.7% (w. b.) were subjected to HPD at 40°C, 48°C, and 56°C for cuboid (20×20×30 mm^3) and cylindrical (20×40 mm^2: length×diameter) shaped samples and it was dried up to moisture content of 9.5% (w.b.). Artnaseaw et al. (2010b) investigated the drying characteristics of the Shiitake mushroom under vacuum HPD at 50, 55, 60 and 65°C and the vacuum pressures of 0.1, 0.2, 0.3 and 0.4 bar. They reported that shiitake mushrooms gave better color and rehydration characteristics. Zhang et al. (2022) dried shiitake mushroom in a heat pump at different four stages temperature 35, 45, 55 and 65°C. They found drying temperature of 55°C affected the rehydration ratio significantly. The optimal drying times of four stages were 2.4, 3.3, 5.6 and 2.6 h, respectively. Malcok et al. (2023) designed an infrared-assisted heat pump drying (IR-HPD) and used for drying of mushroom slices at three different infrared (IR) powers (50, 100, and 150 W) and a fixed drying temperature of 40°C and air velocity of 1 m s^{-1}. They advocated that the use of IR-HPD is an alternative method to obtain high-quality dried mushrooms with good nutritional attributes.

13. QUALITY OF DEHYDRATED MUSHROOMS

There are several changes taking place in quality parameters during drying and storage. The extent of changes depends on the care taken in preparing the material before dehydration and on the process used. Major quality parameters associated with dried food products include colour, visual appeal, shape of product, flavor, microbial load, retention of nutrients, porosity-bulk density, texture, rehydration properties, water activity, freedom from pests, insects and other contaminants, preservatives, and freedom from taints and off-odours (Ratti, 2005). Colour is one of the most important criteria for evaluation of food as it is critical in the acceptance of food products by consumers. Quality of any food product is the ultimately decisive factor of the acceptance and attractiveness of the consumers. The overall quality of foods depends on the nutritional and sensory attributes. The sensory attributes namely, colour, appearance, feel, aroma, taste and texture are the deciding factors. The evaluation of quality of dehydrated mushrooms is very essential for consumer acceptance and marketing. The sensory evaluation helps in ensuring the consumers get consistent, non-defective and enjoyable foods. Sensory evaluation is therefore considered an important analytical tool in the present day competitive corporate environment (Reece, 1979). The two methods most frequently used to directly measure preference and acceptance are the paired comparison test and a 9-point Hedonic scale (Ranganna, 1986). Several researchers in the past have adopted the Hedonic rating test method for the evaluation of sensory quality of fruit, vegetables and mushroom products (Sagar et al., 1999; Rama and John, 2000; Singh et al., 2001; Chandra and Samsher, 2002). Pruthi et al. (1978) reported that the rehydration ratio of tray dried mushrooms (non-sulphited) varied from 3.2 to 4.5 and was the highest in case of unblanched mushrooms. Deshpande and Tamhane (1981) found the rehydration ratio in the range of 4.45 to 5.70. They also reported that mushroom samples dried at 80°C in a fluidized bed dryer gave the highest rehydration ratio of 5.70. These samples also retained very good attractive colour, flavor and texture after rehydration. Mudahar and Bains (1982) studied dehydration of white button mushrooms and found the rehydration ratio of sun dried samples in the range of 2.3 to 2.6:1 as compared to 2.6 to 3.9:1 of the pretreated hot air dried samples. The rehydration ratio of sun-dried samples was lower than hot air dried samples. The discoloration was minimum when KMS and citric acid were mixed together as the medium for immersion after blanching. Nehru et al. (1995) found a maximum rehydration ratio of 5.20 for KMS treated followed by sodium benzoate treated mushrooms (4.90). Suguna et al. (1995) reported lower rehydration ratio and higher browning index values for sun dried mushrooms against hot air-dried mushrooms. Drying temperature of 50°C was optimum to get a good quality product in fluidized bed drying. Blanching as well as blanching plus steeping resulted in minimum browning in fluidized bed drying at 50°C. Dried samples were cooled and packed in lip zip pouches made of 100 gauge polyethylenes. Chandra and Samsher (2002) reported that tray dried mushrooms at 60°C rated the highest sensory score for colour, texture, flavor and overall quality followed by poly house, sun and vacuum drying. Rama and John (2000) determined rehydration ratio of dried mushrooms using methods like sun drying, mechanical drying and microwave drying with different treatments. The fastest rehydration and reconstitution were exhibited by the sample dried without any pretreatment (control). The elasticity of cell walls and swelling power of starch, which are important for good rehydration, are reduced during the treatment, hence the lower rehydration ratio of blanched samples. The quality of the microwave oven dried sample was found to be best. Singh et al., (2001) reported higher rehydration values under fluidized bed drying for button mushrooms. Singh et al. (2007) studied the air-drying characteristic of button mushroom with respect to pre-treatment (EDTA), air temperature (40, 45, 50 and 55°C) and slice thickness (0.5, 0.7, and 0.9 cm) and quality of dehydrated slices were evaluated on the bases of colour and amino acid content. The samples dehydrated at 50°C showed better quality.

14. CONCLUSION

The shelf life of fresh mushrooms is very limited under ambient conditions due to perishable nature. Drying is one of the most used techniques to extend the shelf-life of mushrooms to make it available during off-season. The solar drying, tray drying, vacuum drying, freeze drying and heat pump drying have potential to develop quality dried mushrooms with extended shelf life. The selected drying system should be cost effective with minimum drying time and minimum damage to the products.

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