International Journal of Chemical Studies

P-ISSN: 2349–8528
E-ISSN: 2321–4902
www.chemijournal.com
IJCS 2020; 8(2): 2376-2381

Received: 22-01-2020
Accepted: 24-02-2020

Recent advances in mushrooms preservation

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DOI: https://doi.org/10.22271/chemi.2020.v8.i2aj.9107

Abstract
Mushroom is considered as a functional food rich in both nutrients and medicinal properties. Over the years due to increased recognition of its medicinal and nutritional values and income generating potential the demand for mushrooms has been on the rise. However, mushroom have shorter shelf-life because of their high respiration rate and lack barriers to prevent water loss and microbial attack. Various physico-chemical changes takes place in mushroom during postharvest period like moisture loss, discoloration, texture loss, nutrient loss, microbial spoilage, etc. In order to improve self-life and preserve quality of mushroom, various preservation methods are used which involve thermal, physical and chemical processes. This article highlights recent methods and techniques of preservation of postharvest mushrooms.

Keywords: Mushroom, short shelf-life, chemical processes, thermal processes, physical processes

Introduction
Mushrooms have been an essential part of the human diet and are used as both food and medicine for centuries. They have outstanding attractive taste, aroma and nutritional value, so are considered as functional food, which means they are beneficial to the body not only in terms of nutrition but also for improved health. They are a seasonal and highly perishable crop which are spongy, fleshy, porous, and fruity parts of a fungus, and are mostly grouped as vegetables. Mushrooms are regarded as a commercially valuable source of food due to their bio-active components such as high-quality proteins, vitamins, minerals, unsaturated fatty acids, dietary fibers, delicious flavor and low calorific value. Being a rich source of nutrition and being fat-free, cholesterol-free, and gluten-free; mushrooms are gaining popularity among health-conscious consumers.

Due to increased recognition of its medicinal and nutritional values, coupled with the realization of the income generating potential of fungi through trade, the demand for mushrooms has been on the rise. The global market for mushrooms was valued at $29,427.92 million in 2013. This market is projected to grow at a CAGR of 9.5% to reach more than $ 59.48 Billion in 2021. The most common ones that are produced and consumed are button mushrooms (*Agaricus bisporus*), shiitake mushrooms (*Lentinula edodes*), and oyster mushrooms (*Pleurotus* spp.) and accounted for nearly 76% of the global mushroom market size in 2013.

With a rise in income levels, the demand for mushrooms is bound to increase across all major developing nations such as India, Thailand, and Canada. China has been producing mushrooms at low costs with the help of seasonal growing, state subsidies, and capturing the potential markets such as the U.S., Germany, and France, with processed mushrooms at costs not remunerative to the growers in other mushroom producing countries.

Currently, the total mushroom production in India is approximately 0.13 million tons. The recent production data showing that, the share of button mushroom in India is maximum amounting to 73% followed by oyster mushroom which contributes about 16% (Sharma *et al.*, 2017) [20]. The total white button mushroom produced in India from both seasonal and high tech cultivation units is estimated at 94676 metric tons. At present, highest production of button mushroom is registered from the Punjab followed by Haryana and Maharashtra. These three states producing 43% of total white button mushroom produced in India.

Seasonal cultivation became more popular in Haryana and Punjab region producing more than 8000-8500 tons of white button mushrooms per year. The country's production in 2010 was 1.00 lakh metric tons, of which button mushroom accounted for 89% of the total production, followed by oyster (6%), milky (1%) and others (4%). The present production status revealed that, Maharashtra and Odisha are emerging as the leading states in mushroom production. By considering the present production data, mushroom industry in India recorded an average annual growth rate of 4.3%. Many growers have started adopting the seasonal cultivation of white button mushroom as a livelihood and income generating activity in India. The advantages like nearness to market, availability of raw materials at cheaper price coupled with the availability of good quality of spawn triggering the mushroom production in some parts of India.

Nutritional and medicinal properties of mushrooms

Mushrooms have low calorific value and a good source of non-starchy carbohydrates, protein, dietary fiber, mineral and vitamins (Kulshreshtha *et al*., 2009) [9]. In mushroom carbohydrates (63%) are stored as glycogen, chitin and hemicellulose instead of starch. Mushrooms are also considered as a bank of protein (22%) that includes major essential amino acids and fat (5%) including linoleic acid. Mushrooms are a major source of dietary fiber mixture of polysaccharides (β-glucan), lignin, and other plant cell constituents Mushrooms are a good source of many compounds, including phenolics, vitamins (thiamine, vitamin C, riboflavin, niacin, and tocopherols) and flavonoids and healthy minerals (K and P).

The presence of polysaccharide β-glucans or polysaccharide–protein complexes content in mushroom have great therapeutic applications in human health as they possess many properties such as anti-diabetic, anti-cancerous, anti-obesity, immunomodulatory, hypocholesteremia, hepatoprotective nature along with anti-aging. They also have enormous medicinal attributes such as antibacterial, anti-viral, antioxidant, and hypocholesterolemic (Chaturvedi *et al*., 2018) [3] They helps in preventing colon cancer, divertible diseases, and irritable bowel syndrome. K to Na ratio found in mushrooms is desirable for hypertension patients

Mushroom spoilage

Degree of whiteness is one of the most important quality factors associated with mushrooms and generally the whitest mushrooms command the highest price in market. Mushrooms are highly perishable products; they have a very short life because of their high respiration rate and lack barriers to prevent water loss and microbial attack. Moulds, bacteria, enzymatic activity and biochemical changes can cause spoilage during storage. Mushrooms lack a protective epidermal structure to prevent excessive moisture loss and therefore have very high transpiration rates. The increased weight loss is also attributable to growth related metabolism of the mushrooms and the utilization of intracellular nutrients. Storage of mushrooms affects their quality in the following ways: darkening of the tissue, elongation of the stems, opening of the caps and hardening of the flesh. Due to high moisture and protein content fresh mushrooms start deteriorating very fast soon after harvesting, often rendering the produce unsalable. Development of brown color is first sign of deterioration caused by polyphenol oxidase enzymes acting on phenolics, converting them into quinones, which combine with amino acids to form highly coloured complexes (Kaushal and Sharma, 1995) [10]. Weight loss in mushrooms is a common phenomenon which occurs mainly due to moisture loss and loss of carbon reserves due to respiration.

Mushrooms lack a protective epidermal structure to prevent excessive moisture loss and therefore have very high transpiration rates. The increased weight loss is also attributable to growth related metabolism of the mushrooms and the utilization of intracellular nutrients. The initial firmness was retained during the first two days of optimal storage due to the production of chitin in the tissues. At least two mechanisms may be involved in the softening of mushroom tissues: the loss of cell rigor due to changes in membrane permeability and the loosening of the hyphal network on maturation of the mushrooms. It is surmised that cell turgidity contributes to the toughness of a fresh mushroom, and then it is likely that the firmness drops sharply when the mushroom loses water. Moreover, texture losses decrease when the CO_2 concentration was increased. CO_2 concentration higher than 10% seems to be the most appropriate to maintain firmness. Protease enzyme activity also influences mushroom quality by contributing to sporophore texture loss. Another possible explanation for the decreased firmness in the button mushrooms could be a loss of turgor in the gills during storage.

Their high respiration rate and high water content make them prone to microbial spoilage and enzymatic browning. Gram-negative microorganisms and yeasts have been associated with mushroom spoilage. Several studies reported high microbial load on fresh harvested mushroom and Pseudomonas is the most abundant (72-90%) bacterial genus in mushrooms. *P. tolaasii* and *P. reactans* being the major species responsible for bacterial blotch and they are also believed to have a partial effect on colour deterioration. Members of *Enterobacteriaceae* family and lactic acid bacteria are also associated with spoilage of mushroom.

Preservation technologies of postharvest mushroom

The short shelf-life of mushrooms is a disadvantage that limits its economic value. During the postharvest stage, mushrooms experience a series of quality degradation, for example, moisture loss, discolouration, texture changes, off flavour and nutrition loss. Several factors have an impact on mushrooms' quality during postharvest. These factors can be divided into two categories: the internal factors related to mushroom itself (i.e., water activity, respiration rate, and microbial activity) and the external factors related to storage conditions (storage temperature, relative humidity). Zhang *et al*., (2018) [23] reviewed recent trends in preservation of postharvest mushrooms. Several preservation processes and methods could effectively reduce post-harvest quality deterioration and achieve shelf-life extension of mushrooms (Table 1.).

Table 1: Methods of mushroom preservation

Processes	Techniques	Methods
Thermal Processes	Drying	Hot Air Drying, Microwave Drying, Freeze Drying, Vacuum Drying, etc.
	Cooling	Vacuum Cooling.
Physical Processes	Packaging	Modified Atmospheric Packaging.
	Irradiation	Gamma, Electron-beam and UV Irradiation.
	Pulse Electric Field	
Chemical Processes	Washing	Sulphite Solutions, Citric Acid, Hydrogen Peroxide, etc.
	Coating	Chitosan, $CaCl_2$, Alginate, etc.
	Ozone	
	Electrolyzed Water	

Thermal processes

Thermal processes (i.e., drying and cooling) are typical methods which could significantly retard mushrooms quality degradation by controlling storage temperature and water activity (Pei *et al*., 2014a, b).

Drying

Drying is a common preservation method for mushrooms. Recent applications of different drying techniques in mushrooms preservation are shown in Table 2.

Table 2: Drying systems in mushroom preservation

Drying Systems	Results
Solar assisted heat pump drying	Less energy input with high coefficients of performance
Infrared hot air drying	Increases hot air temperature from 50 to 70 °C
Microwave drying (MD)	Minimum drying time and intact quality attributes
Hot air drying (HAD), Vacuum drying (VD)	Dried products with increase of the total free amino acids.
Microwave vacuum drying (MVD)	Maintain nutrient and colour attributes; and taste-active amino acids.
Combined drying of hot air and microwave vacuum drying	Better dried product quality (colour, texture, density, porosity and rehydration).
Freeze drying (FD), freeze drying combined with hot air drying (FD + AD), freeze-drying combined with vacuum drying (FD + VD),	No changes in colour, average density and hardness
freeze drying combined with microwave vacuum drying (FD + MVD)	Reduces drying time by 35%. and better nutrient retention

Conventionally, mushrooms are dried by solar drying and hot air drying. However, the heat transfer from food surface to the centre is slow during solar drying and hot air drying. Thus, a long dehydration time is required, leading to quality degradation of final dried products. Hot-air drying at higher temperatures has been reported to have some adverse effects like loss of cell permeability, denaturation of proteins, crystallization of starch and hydrogen bonding of macromolecules which collectively, or alone, affect the re-constitutional quality of the mushrooms.

Several advanced and combined drying techniques have been explored to improve drying efficiency and product quality of mushrooms. Microwave drying is an advanced drying technique with the use of electromagnetic waves in the frequency range from 300 MHz to 300 GHz (Sun, 2012) [18]. Compared to hot air drying, microwave drying can significantly reduce the drying time.

Freeze drying (FD) could produce high-quality products based on water sublimation, water is removed from the solid phase to vapour phase directly during the drying process. Freeze drying takes place at a low temperature, heat-sensitive properties of products such as vitamins could be maintained without heat damage (Pei *et al*., 2014a, b) [16, 17]. Due to the sublimation of ice crystals, freeze-dried products have a porous structure. One of the main disadvantages of FD was the high capital cost and high energy consumption for the vacuum system and refrigeration system, with a small throughput and a low drying rate. The cost of removal of water in freeze-drying is almost 10 times than that in hot air drying

Different drying methods have different effects on mushrooms' volatile compounds content, total free amino acids content, nutrient retention, colour maintain as well as water holding capacity. Compared with hot air, vacuum, microwave and microwave vacuum drying, microwave vacuum drying helped to produce more uniform dried products with a larger amount of taste-active amino acids residual.

Cooling

Cooling is an essential process to extend the storage life of agri-food products. At 0 °C, mushrooms respiration rate is three times lower than that at 10 °C, immediate field heat removal from mushrooms after harvest can slow down their deterioration, increasing their shelf life for up to 9 days (Diamantopoulou and Philippoussis, 2015) [4]. There are various cooling techniques available, among them, vacuum cooling is a rapid cooling technique based on moisture evaporation of product under vacuum conditions. The porous structure and high moisture content of mushrooms make them suitable to be vacuum-cooled. Compared to conventional cooling methods, vacuum cooling can reduce the mushroom cooling time significantly and can lower the microbial growth rate (Ozturk *et al*., 2017) [14]. However, weight loss is a major disadvantage in vacuum cooling of mushrooms. In addition freeze drying can be used in preservation and storage of mushrooms.

Physical processes

Packaging

Modified atmosphere packaging (MAP) is a popular packaging method in the food industry, which has been used to effectively preserve mushrooms. It uses a modification of atmosphere within the food packages to extend the shelf-life of products. Modified atmosphere storage refers to the technique of sealing the actively respiring produce in polymeric film packages, so that the gas composition inside the package is modified depending upon the respiration rate of the produce and permeability of the packaging film. The metabolic process of the agricultural products interacts with the diffusion process of the packaging materials to generate a suitable atmosphere for product preservation (Oliveira *et al*., 2015) [13]. The decrease in O_2 and the increase in CO_2 concentration in MAP inhibit the growth of microorganisms on fresh food. For fresh mushrooms preservation, MAP is considered as an effective, simple and economical packaging technique. A low O_2 concentration could reduce mushrooms respiration rate, retard cap opening and diminish discolouration. A number of factors, such as the properties of the packaging materials, ambient gas composition, the surface area of the sample as well as storage temperature and humidity can influence the storage effect of MAP. Recent applications of MAP on mushroom preservation are shown in Table 3.

Table 3: Applications of MAP in mushroom preservation

Film Material	Results
Perforation mediated Low density polyethylene film	Increases shelf life and firmness, total phenolic and antioxidants of mushroom are preserved
Biorientated polypropylene bags	Increases shelf life, maintain firmness and delay browning and cap opening
Poly lactic acid (PLA) and Poly ε -caprolactone (PCL) blend films with different cinnamaldehyde contents	Low weight loss of mushrooms and maintain high CO_2 levels
Paraffin-based thermo regulating material (TRM) microencapsulated in melamine powder (MMP)	Maintain the internal temperature of the package at 5 °C. MMP package has sufficient thermal buffering capacity
Low density polyethylene	Reduce mushroom browning index and increase total phenolic content and total antioxidant activity

Diffusion channel storage system, a method of modified atmosphere storage technique works based on the principle of diffusion of gases through the channel. Diffusion channel is a hollow tube or channel fitted with the airtight storage chamber in which produce is stored, the other end of which is exposed to the ambient air. In diffusion channel storage system, the storage chamber is impermeable to gas and the exchange of gas takes place only through the diffusion channels. The presence of diffusion channel controls the flow of gases on either direction (i.e. from storage atmosphere to ambient atmosphere and vice versa) thus maintaining the optimum gas composition.

Irradiation

Food irradiation is regarded as a breakthrough after pasteurization. During the process, food is exposed to ionizing radiation to eliminate microorganisms or insects, as a result, sensory and nutritional properties of food products are preserved. Radiation sources such as gamma irradiation, UV irradiation and electron-beam were used to preserve mushrooms quality (Roberts, 2014) [19].

Gamma irradiation has been proved to be a safe processing technique for a number of food products by the United States Food and Drug Administration (USFDA). Gamma irradiation (up to 1 KGy) is a useful alternative for quality maintain and shelf life extension of wild edible mushroom. It have an effect on diminishing enzymatic browning by retarding the polyphenol oxidase activities in mushrooms (Donnadieu *et al*., 2016) [5]. However, the use of gamma irradiation could cause variation in chemical composition of mushrooms (Fernandes *et al*., 2017) [6]. Ultraviolet-C (UV-C) irradiation reduces microbial counts and cap opening of mushrooms. For electron-beam treatment, irradiation level of 1 kGy have a positive effect on shelf-life extension of mushroom slices, by reducing aerobic and psychrotrophic populations (Yurttas *et al*., 2014) [22].

Pulsed electric field and ultrasound

Pulsed electric field (PEF) is a non-thermal processing method to preserve the natural quality of food products. The use of short pulses of electricity in PEF treatment can inactivate microorganisms and enhance the mass transfer process. In PEF, the electric field strength creates transient pores in biological membranes, leading to irreversible cell disruption (Roselló-Soto *et al*., 2017), which helps to kill the microorganisms as well as assist total polyphenols extraction processes of mushroom (Parniakov *et al*., 2014) [15].

Ultrasound is an alternative technique to increase the mass transfer for various processes by affecting physical properties of the mushroom tissue. Ultrasound treatment takes the advantages of cavitation effect, in which the gas bubbles are induced by the ultrasound collapse, generating high energy shock waves and intensive shear forces (Guerrero *et al*., 2017) [7]. A combination of low-concentration acidic electrolyzed water and ultrasound are proved as an effective method for retarding enzymatic browning and firmness maintenance in fresh mushroom slices (Wu *et al*., 2018) [21].

Chemical processing

Washing with antimicrobial agents

Washing is an essential treatment to remove attached casing soil and microorganisms from mushrooms surface to inhibit microbial spoilage. However, the washed mushrooms generally have a higher moisture content, which is even more vulnerable to microorganisms when compared to unwashed mushrooms. Therefore, chemicals such as antimicrobial agents are generally added to the washing water to remove casing soil and to diminish mushrooms quality deterioration. In order to improve the color and enhance the shelf life washing of mushrooms with various anti browning inhibitors is recommended.

Sulphite solutions such as sodium metabisulphite, sodium chloride and sodium hypochlorite were used as washing agents to remove unwanted casing particles so as to enhance the whiteness of mushrooms. However, the use of sulphite has been reduced and replaced by stabilized chlorine dioxide in mushrooms processing, as washing with sodium metabisulphite showed a negative effect on mushrooms quality.

Citric Acid

Citric acid was the most effective solution for mushroom quality preservation, in term of controlling weight loss, postharvest maturity index and microbial growth. Citric acid is widely used as an additive and as an antimicrobial by virtue of their low pH in food industry. Citric acid is used in hot water blanching of mushrooms due to its copper chelating effect.

EDTA

Like citric acid EDTA is also has the potential to inhibit microbial growth. Soaking in 0.5% citric acid and 0.5% ascorbic acid has produced comparatively more acceptable product taking into account all the quality parameters.

Hydrogen peroxide (H_2O_2)

The immersion in hydrogen peroxide solution followed by dipping in a solution of enzymatic browning inhibitor was found to be beneficial for extending the shelf life of whole mushrooms. Use of hydrogen peroxide and citric acid was found to be effective in reducing weight loss as compared to EDTA.

Combined effect of chemical treatment and MAP, resulting in maintenance of tissue firmness and sensory quality, inhibition of lipid peroxidation and better retention of phenolics and antioxidant ability, and extending their postharvest life up to 25 days when stored at 4 °C.

Coating

Coating with alginate helps to maintain the firmness of mushrooms, to delay disco E. colilouration and cap opening, and to inhibit the loss of soluble solids concentration, total sugars and ascorbic acid of mushrooms. The shelf-life of mushrooms was successfully extended to 16 days with alginate coating. Chitosan is an alternative coating material for a wide range of food products for it is a biodegradable and biocompatible polysaccharide extracted from natural resources. Treatment with chitosan-glucose complex coating maintained tissue firmness, reduced microbial counts and inhibited increase of respiration rate in mushroom within 16 days of storage at 4 °C. Combination of coating of aloe vera and gum tragacanth was the most eff ective approach in minimize mushroom weight loss, colour changes and texture softening. Tragacanth gum combined with *Zataria multiflora* Boiss. essential oil helped to maintain 93.47% of mushrooms tissue firmness, reduced microbial counts and decrease browning index of fresh mushrooms after 16 days of storage at 4 °C (Nasiri *et al*., 2017) [12].

Ozone

Ozone is a powerful antimicrobial agent to extend shelf-life of food. Due to the strong oxidation capacity, ozone inactivates microorganisms rapidly after reacting with inter-cellular enzymes and cell components (Prabha *et al*., 2015) [18]. After decontamination, ozone is quickly decomposed into oxygen, as a result, there are no undesirable residues left. Gaseous ozone has been regarded as a safe sanitizing agent by the USFDA to be directly contacted with food. Results showed that 60 min exposure to gaseous ozone with concentrations of 2.8 and 5.3 mg/L caused reduction in aerobes, *Salmonella*, *L. monocytogenes* and *E. coli*: 157 (Akata *et al*., 2015) [2].

Chlorides

Chlorides decrease the pH of the solution resulting in the increased inhibition of enzymes such as poly-phenol oxidase and catalase. Mushrooms when dipped in the solutions of calcium chloride and sodium chloride, the solutions make oxygen unavailable for the reaction to take place resulting in retard diffusion of oxygen. The action of calcium chloride and sodium chloride in preventing browning is might be due to the presence of chlorides. Addition of calcium chloride delays the occurrence of browning and also acts as a firming agent in the fruits and vegetables.

Electrolyzed water

Electrolyzed water (EW) is another promising disinfectant generated by electrolysis of a salt solution. The antimicrobial activity of EW is determined by the concentration of free available chlorine, which forms the hypochlorous acid (HCLO), the oxidation-reduction potential (ORP) and their combined eff ect (Lee *et al*., 2014) [11]. Compared to other disinfectants, EW treatment has less aggressive corrosion on food quality. In addition, EW could be reverted to ordinary water by diluting with tap water. Result showed that the use EW eff ectively inactivate microbial activities and had the best performance in maintaining mushrooms whiteness index and texture, and diminishing weight loss (Aday, 2016) [1].

Sorbitol

Sorbitol has a considerable water holding capacity. During the modified atmospheric packaging (MAP) storage it has been found that sorbitol can keep good color and reduce the water loss. Mushrooms irrigated by $CaCl_2$ and treated with a small quantity of sorbitol demonstrated reduced compression.

Sorbitol is more efficient for increasing antioxidants enzyme and scavenging ROS which helps mushroom to maintain good post-harvest quality.

Essential Oils

Mushrooms treated with the water extract of freshly prepared *Lavendula stoechas* and *Lavendula angustifolia* exhibited strong inhibitory effects against tyrosinase activity. Cinnamaldehyde has been considered as the major compound in the essential oil of cinnamon tree with a significant anti-fungal and antioxidant, as well as antimicrobial activity. Application of cinnamaldehyde has been reported to be beneficial in preserving the quality of intact button mushrooms. It was observed that fumigation treatment of *Agaricus bisporus* with 5 mL/L cinnamaldehyde in relation to browning could delay cap opening, reduce microorganism counts and improve the accumulation of phenolics as well as ascorbic acid. Successful inhibition of senescence in cold-stored button mushroom was observed with essential oils fumigation treatments, such as clove, cinnamaldehyde and thyme. Together they kept the sensory characteristics within acceptable limits throughout storage. Moreover, essential oils fumigation not only possessed antimicrobial properties and maintains firmness during storage but also exhibits the capability to increase the total phenolics and ascorbic acid contents. Thus, these natural products have the potential to preserve the quality and safety of button mushroom.

Future scope

The application of novel techniques and the combination of diff erent techniques with a low capital cost or less processing time should be encouraged to further enhance mushrooms postharvest quality.

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