Postharvest Biology and Technology 132 (2017) 62–70

Contents lists available at ScienceDirect

Postharvest Biology and Technology

journal homepage: www.elsevier.com/locate/postharvbio

Fresh-keeping effects of three types of modified atmosphere packaging of pine-mushrooms

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ARTICLE INFO

Keywords:
Modified atmosphere packaging (MAP)
Tricholoma matsutake
Mushrooms
Fresh-keeping
Polyethylene (PE)
Polyvinyl chloride (PVC)

ABSTRACT

Pine-mushrooms are one of the most prized mushrooms. They are difficult to store. Modified atmosphere packaging has been widely used in mushroom storage, but few reports are associated with pine-mushrooms. The effects of polyvinyl chloride (PVC), silicon windows (SW) and polyethylene (PE) packaging materials on the sensory of texture, senescence, browning and odor changes have been evaluated and the preliminary mechanisms have been studied. Texture changes were most efficiently delayed by PE as a result of the lowest respiration rates and weight loss. Senescence was most efficiently delayed by PE and PVC as a result of the raised CAT activities and ascorbic acid contents. Browning was most efficiently delayed by PE as a result of the decreased PPO activities. Odor changes were most efficiently delayed by SW, the decreased ammonia contents may be important reason. Different water vapor and gas transmission properties of packaging may determine the different pine-mushroom sensory.

1. Introduction

Pine-mushrooms (*Tricholoma matsutake* Sing.) are one of the most prized mushroom species and still remain wild and can't be cultivated (Murata et al., 2015). Pine-mushrooms are commonly found in northeast Asia, southwestern China and parts of central and northern Europe (Endo et al., 2015). In oriental countries, pine-mushrooms have long been consumed either raw or cooked as a top-grade food for their abundant aroma and flavor (Cho et al., 2010, 2006b). Pine-mushrooms have also been used as traditional Chinese medicine for the prevention and treatment of diseases for several thousands of years (Ishihara et al., 2003; Yang et al., 2009). Recently, polysaccharides isolated from pine-mushrooms have been proven to have antimicrobiological, antioxidant, antitumor and immune activities (Ding et al., 2010; Li et al., 2015; You et al., 2013). Because of the nutritional and delicious features of *T. matsutake*, the prices are inflated up to 50–400 USD/kg according to their grades (Lim et al., 2007). The data from China Customs show that the annual exported sales of pine-mushrooms in China were estimated at 5.9×10^9 USD (Data, 2015).

Although pine-mushrooms are favored and expensive, they are very difficult to store. They lose edibility in 1–2 days at ambient temperature because of their thin epidermal structure, high respiration rate and high moisture content, features also observed in other wild mushrooms (Mahajan et al., 2008). Even at low temperatures, aroma and edible qualities of pine mushrooms decreased fast and deteriorate in about 10 days in general. In China, the separate origins (rural mountain area in the southwest) and markets (coastal city in the east or overseas) further create new conflicts related to the short storage life.

MAP has been widely used for the storage of mushrooms such as *Lactarius deliciosus*, *Lentinus edodes*, *Lentinus edodes* and *Pleurotus florida*, but there are few studies associated with *T. matsutake* (Andrés et al., 2014; Jafri et al., 2013; Li et al., 2014). Different MAP packaging materials, such as PVC, PE and PP, modulate different transmission rates of water vapor, CO_2 and O_2, MAP controls the respiration rate of mushrooms, thus preserving the quality and extending the storage time of mushrooms. Because of the diversity of mushroom's physiological characteristics, appropriate materials must be designed to keep suitable O_2 and CO_2 level and maintain proper humidity (Montanez et al., 2010).

The objectives of this work are to compare the fresh keeping effects of three MAP materials (PVC, SW and PE) and investigate the relation between separate quality traits (texture, senescence, browning, odors) and the packaging features in pine mushrooms under 2 °C.

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http://dx.doi.org/10.1016/j.postharvbio.2017.05.020
Received 5 April 2017; Received in revised form 27 May 2017; Accepted 29 May 2017

2. Materials and methods

2.1. Experimental setup

Pine-mushrooms were collected from Diqing, Yunnan province in China and immediately pre-cooled and transported to our laboratory within 24 h. According to their appearance, extremely large or small and damaged mushrooms were discarded. Subsequently, mushrooms were classified according to a four-grade standard (Cho et al., 2006a). To simulate the actual sales in China, pine-mushrooms of the first grade (more than 8 cm long with an unopened pileus) and second grade (6–8 cm long, but with irregular widths and unopened pilei) were chosen as the materials for this study. Then, the mushrooms were divided into four groups, and evenly distributed the first and the second grades to different groups. The first group was unpackaged and placed in polystyrene boxes, and the second, third and fourth groups of samples were placed in sealed polyvinyl chloride packaging (PVC), polyethylene packaging (PE), and polyvinyl chloride packaging with silicon windows (SW). Three packaging materials were produced in the workshop of Jinan Fruit Research Institute using an SFM2800-1 automatic hollow extrusion blow film machine (Shandong Guanhua Co., Ltd.) and a high-frequency sealing machine (Shandong Guanhua Co., Ltd.). The size and thickness of the packaging were designed according to the common commercial packaging of pine mushroom (Table 1). Packaging sizes (Table 1) were designed as 500 g pine mushrooms per packaging which were the common retail packaging in China. Silicon windows size were designed to achieve moderate O_2 and CO_2 transmission rates. No adjusted gas was flush packages before sealing as this technology is still not available in most of the producing areas in China. All samples were stored at 2 ± 1 °C for 15 days. Pine-mushrooms were observed and sampled at 0, 3, 6, 9, 12, and 15 days. In total, nine replicates per packaging types were sampled and tested at each sampling point.

2.2. Physical properties of packaging

Water vapor permeability was measured with a HYDRO7310 membrane water vapor permeability tester (Labthink, China) using the methods indicated in the instructions. In brief, candidate films were cut into 33 cm^2 circular specimens. Then the test dishes containing distilled water were sealed with the cut films and put into the tester. Under 25 °C, a constant humidity difference is generated between two sides of the test specimen. The water vapor permeates through the specimen and into the dry side. By measuring the weight changes of the test dishes in different time, Water vapor permeability can be obtained.

The gas permeability rates of O_2 and CO_2 were measured with a GASTRA7100 membrane gas permeability tester (Labthink, China) using the methods indicated in the instructions at 25 °C. In brief, candidate films were cut into 38.48 cm^2 circular specimens. The specimens have been placed tightly between two chambers. Evacuating created a lower pressure in one chamber, and feed O_2 or CO_2 in another chamber. By monitoring and measuring the pressure in the low-pressure side, a variety of barrier parameters of the tested specimen can be obtained.

The water vapor, O_2 and CO_2 permeability per packaging in 24 h were calculated as:

Permeability per Packaging (g or mL) = [(SW Area × Permeability Rate of SW) + (Film area × Permeability Rate of Films)] × Time.

2.3. Headspace gas composition

A Dansensor gas analyzer (PBI, Denmark) was used to determine the O_2 and CO_2 concentrations in the headspace of the packaging. The needle of the Dansensor penetrated through the latex tubes that were sealed through the top of the packaging.

2.4. Respiration rate and weight loss

A JFQ-3150H fruit and vegetable respiration analyzer (junfanglihua, China) was used to determine the respiration rates of pine-mushrooms at 2 °C. Six mushrooms were chosen as one group (3 first grade and 3 s grade). After each group was weighed,

The weights of pine-mushrooms in different groups were recorded at the beginning of storage and on each sampling day. The results were expressed as the percentage losses of the initial packaging weight of the samples.

The mushrooms were placed gently in the sample tank where the respiration rates were automatically calculated as the CO_2 production per weight and per time using the infrared spectroscopy detector.

2.5. Antioxidant enzyme, polyphenoloxidase (PPO) activity and malondialdehyde (MDA) contents

CAT, POD and PPO activities were analyzed as previously described with some modifications (Tao et al., 2007). All enzyme extraction procedures were conducted at 4 °C. Mushrooms from six fruits were sampled for each replicate (in total, there were nine replicates for each sample). Crude enzyme extracts were prepared as follows: 2.5 g of fresh weight mushroom tissue was ground in 25 mL of 0.05 mol L^{-1} phosphate buffers (pH 7.8) and then centrifuged at 15,000 × *g* for 15 min. The supernatants were used to determine CAT, POD and PPO activities. Total protein was measured as a quantitative standard of the crude enzyme extracts according to the Bradford method (Bradford, 1976), using bovine serum albumin (BSA) as a standard.

For POD activity, the reaction mixture consisted of 1 mL of crude extract and 3 mL of reaction solution (50 mL of 0.1 mol L^{-1} sodium phosphate (pH 6.4), 0.028 mL of guaiacol, and 0.019 mL of 3% H_2O_2). The activity was determined by measuring the increase in absorbance at 460 nm according to previous methods. One unit was defined as DA of 0.001 per 30 s (Sun et al., 2013).

PPO activity was determined by adding 0.1 mL of the enzyme preparation to 5.0 mL of 0.1 mol L^{-1} catechol substrate, and the increase in absorbance at 398 nm was measured immediately. One unit was defined as DA of 0.01 per min (Sun et al., 2013).

MDA content was measured according to previous method with modifications (Heath and Packer, 1968). Absorbencies of the aqueous phase at 450 nm, 532 nm and 600 nm were measured. The MDA content in the aqueous phase was calculated according to the following

Table 1
The physical properties of PVC, SW and PE packaging.

	Packaging External Surface Area (m^2)	Silicon Windows Area (m^2)	Packaging Thickness (Silicon Windows Thickness) (mm)	Water Vapor Total Flow per packaging in 24 h (WVTF) (g)[a]	O_2 & CO_2 Total Flow per packaging in 24 h (OCTF) (g)[a]	
					O_2	CO_2
PE	0.0528	0	29.3 ± 0.7	0.53	0.36	2.95
PVC	0.0528	0	33.6 ± 0.9	4.21	0.24	3.18
SW	0.0528	0.002	33.6 ± 0.9 (410 ± 15)	5.07	1.57	5.51

[a] All the measurements were conducted at room temperature and 0.1 MPa.