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Influence of different storage conditions on physical and sensory properties of freeze-dried *Agaricus bisporus* slices

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ABSTRACT

To explore the influences of storage conditions on freeze-dried *Agaricus bisporus* slices, the dynamic changes of physical and sensory properties under different conditions (37 °C, 85% RH; 25 °C, 55% RH; ambient temperature) were investigated. The results showed that the samples stored under 37 °C, 85% RH (HT) had sparser microstructure, smaller micro-pores, poorer rehydration, lower hardness and lower fracturability. Color examinations revealed that HT induced whiteness deterioration, this was as a result of phenolic substance oxidation and a weaker protection of citric acid. Umami taste of HT samples was rapidly lost owing to the decrease of 5′-GMP and MSG-like amino acids. Moreover, aroma information from E-nose revealed the superiority of storage conditions, 25 °C, 55% RH (RT) and ambient temperature (AT) were considered as better conditions in retaining the initial volatile compounds. In summary, RT was considered as the optima condition for the storage of freeze-dried *A. bisporus* slices.

1. Introduction

Agaricus bisporus (*A. bisporus*), or button mushroom is an edible fungus with the largest planting area and the most abundant production in the world (Jiang et al., 2011). However, fresh *A. bisporus* has little physical barrier against mechanical damage and microbial attack leading to a series of quality problems, such as color changes, off-flavors and microbial spoilage, all of which would affect the marketability and consumers acceptance (Gholami, Ahmadi, & Farris, 2017). Drying extends shelf-life and food security by reducing water content and water activity. Consequently, enzyme activity and microbial growth is inhibited, and the cost of transportation and storage also decreased owing to lower weight (Grant-Preece et al., 2018; Prosapio & Norton, 2017). Freeze drying is considered as one of the most effective drying method for food preservation, which results in high quality dehydrated fruits and vegetables (Ratti, 2001).

According to reported studies, dried mushrooms could not be stored for more than 12 months owing to severe quality deterioration (Jaworska, Pogoń, Bernaś, & Skrzypczak, 2014). Despite longer shelf-life of freeze-dried *A. bisporus*, changes in color and flavor compounds remain the main problems affecting its marketing and economic value. Studies on the effective drying methods and storage of fresh mushrooms have been conducted. For the storage of freeze-dried *A. bisporus* slices, research is usually focused on moisture state and freezing conditions of freeze-dried *A. bisporus* in evaluating its storage stability (Shi, Wang, Zhao, & Fang, 2012). However, to the best of our knowledge, systematic studies on changes in color, texture, nutrition and taste during storage of freeze-dried *A. bisporus* remain unexplored.

Traditional dried mushrooms, such as *Lentinus edodes* and *Agrocybe aegerita*, are usually transported and stored under ambient temperature and packed in polyethylene packages or are not packages at all. Proper storage methods avoid possible damages and maximally retain the product quality, hence maintain the product market value (Nasiri, Barzegar, Sahari, & Niakousari, 2017). In addition, sensitivity of factors under different storage condition contributes to research on protecting storage quality. Therefore, the work gains paramount importance.

In the present study, changes in color, texture, nutrition and taste of freeze-dried *A. bisporus* slices were studied. Based on color and flavor compounds changes, the best storage method for freeze-dried *A. bisporus* slices was obtained which eventually reduces material and economic losses.

2. Materials and methods

2.1. Sample preparation

Fresh *A. bisporus* used in this study were harvested from a

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commercial farm (Jiangsu Tianfeng Biological Technology Co., LTD, China), and transported to the laboratory within two hours. After 4 h of precooling, *A. bisporus* with removed stems were sliced to a thickness of 5 mm, distributed uniformly in a single layer on a tray (5 kg/m^2), and placed into a −80 °C freezer for over 8 h (Model 900, Thermo Scientific Forma Ultralow Freezer). The samples were then lyophilized in a freeze dryer (Labconco Equipment Co., Kansas, The USA) until moisture content was less than 5%. The drying conditions were set as freeze-drying plate temperature: 40 °C, vacuum pressure: 100 Pa, and cold trap temperature: −83 ± 1 °C.

The dried *A. bisporus* slices were randomly packaged in normal PE packing bag (20 g/bag). To simulate common storage environment for dried foods, all packages were sealed and then respectively stored in the following three conditions:

Constant room temperature and humidity (RT) (25 °C, 55% RH)
Constant high temperature and high humidity (HT) (37 °C, 85% RH)
Variable ambient temperature and humidity (AT) (12–28 °C, 50%–90% RH)

Storage time of 25 days was chosen owing to the spoilage of freeze-dried *A. bisporus* under high temperature and high humidity, which is on day 25. Three bags stored under each storage environment were used to analyze the physiological and biochemical properties of *A. bisporus* every 5 days during storage.

2.2. Determination of physical properties

Moisture content of the samples was determined by an oven method (Shanghai Sujin Equipment Co., Ltd, Shanghai, China). The dried sample (5 slices) was rehydrated by immersion in 100 mL of distilled water at 25 ± 1 °C for 10 min, and rehydration were evaluated using a mass balance. The weight of samples was recorded and the rehydration ratio (RR) was calculated according to Eq. (1):

$$RR = \frac{W_r}{W_d} \quad (1)$$

Where W_r (g) is the weight of rehydrated sample, W_d (g) is the weight of freeze-dried sample before rehydration. The results are the average of three determinations.

Texture Analyzer (Model: TA-XT2i plus, Stable Micro Systems, UK) was used for textural analysis. Ten samples of uniform size were selected for textural analysis. The superficial area of the samples were standardized as length of 5 ± 1 cm and width of 2.5 ± 0.5 cm. Textural analysis based on hardness and fracturability was conducted under the following instrument parameters: probe model: p/5, pre-test speed: 2 mm/s; test speed: 1 mm/s; post-test speed: 10 mm/s; strain: 75% of sample height.

2.3. Scanning electron microscopy (SEM)

Samples were placed in liquid nitrogen and cut into small cube, glued onto the holder of a sputter coater (JFC-1600, Tokyo, Japan). Samples were then photographed using an H-7650 scanning electron microscope (Hitachi High Technologies Corporation, Tokyo, Japan) at an accelerating voltage of 80 kV, mag 1000×.

2.4. Color measurement, total phenol content, PPO and POD activity

The color change of freeze-dried *A. bisporus* slices was determined by a colorimeter (Konica Minolta Sensing Inc., Osaka, Japan). The whiteness of sample powder was obtained by substituting the values of L*, a* and b* into the following equation from the standard of CIE:

$$\text{Whiteness} = 100 - [(100 - L^*)^2 + a^{*2} + b^{*2}]^{1/2} \quad (2)$$

Total phenol content (TPC) was determined according to a previously reported method (Do et al., 2014) with slight modifications, the freeze-dried extract was dissolved to a concentration of 20 mg/mL. The extracts were measured at 760 nm and gallic acid was used as a standard. The activities of polyphenol oxidase (PPO) and polyphenol peroxidase (POD) were determined using assay kits (Nanjing Jiancheng Bioengineering Institute, China) according to the manufacturer's instructions (Xing et al., 2015; Zeng, Li, Li, & Zhao, 2016). The results presented as averages of three determinations.

2.5. Soluble sugar content and protein concentration

Freeze-dried *A. bisporus* powder (0.1 g) was mixed with 1 mL of distilled water and boiled for 10 min, then centrifuged at 4000 × g for 10 min. Supernatant was isolated and sugar content was determined by anthrone–sulfuric acid assay (Le & Stuckey, 2016) using sucrose as standard. The protein concentrations was determined by a total protein quantitative assay kit (Nanjing Jiancheng Bioengineering Institute, Jiangsu, China) (Xing et al., 2015). The results were expressed as averages of three replications.

2.6. Non-volatile flavor compounds assay

2.6.1. Free amino acid, 5′-nucleotide and organic acid assay

Amino acid composition was examined by the method of Liu et al. (2014). Samples were digested with 6 mol/L HCl at 110 °C for 24 h in sealed tubes for acidic hydrolysis. Consequently, free amino acids content was determined using the automatic amino acid analyzer (Hitachi L-8900, Japan). The content of 5′-nucleotide and organic acids were determined according to our previous method (Pei et al., 2014). Each 5′-nucleotide and organic acid was identified using authentic 5′-nucleotide and organic acid (Aladdin Reagent Co., Ltd, Shanghai, China) and quantified using a calibration curve of the authentic compound relative to external standards. The results of these evaluations were then presented as an average of three replicates.

2.6.2. Equivalent umami concentration

The equivalent umami concentration (EUC, g MSG/100 g) is the concentration of MSG equivalent to the umami intensity given by a mixture of MSG-like amino acids and the 5′-nucleotide and is represented by the following Eq. (3) (Chen & Zhang, 2007).

$$Y = \sum a_i b_i + 1218(\sum a_i b_i)\cdot(\sum a_j b_j) \quad (3)$$

Where Y is the EUC of the mixture (g MSG/100 g); a_i is the concentration (g/100 g) of each umami amino acid (Asp or Glu); a_j is the concentration (g/100 g) of each umami 5′-nucleotide (5′-IMP, 5′-GMP or 5′-AMP); b_i is the relative umami concentration (RUC) of each umami amino acid relative to that of MSG (Asp, 0.077 and Glu, 1); b_j is the RUC of each umami 5′-nucleotide relative to that of MSG (5′-IMP, 1; 5′-GMP, 2.3 and 5′-AMP, 0.18), and 1218 is a synergistic constant based on the concentration (g/100 g) used.

2.7. Electronic nose analysis

E-nose system (FOX 3000, Alpha MOS, Toulouse, France) with 12 sensors was used to discriminate fingerprint of different odor as described in our previous study (Yang et al., 2016).

2.8. Statistical data analysis

The measured data were analyzed by SAS system, Version9.0 (SAS Institute, Cary, NC). Least significant differences (LSD) multiple comparison tests were then performed with a 95% confidence level.

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