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Effects of different drying methods on the product quality and volatile compounds of whole shiitake mushrooms

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ABSTRACT

Various drying methods play important roles in the preservation of foods. However, how the different drying methods affect the quality of some foods is not clear. This paper evaluates the effects of hot air, vacuum, microwave, and microwave vacuum drying techniques on important qualities and volatile compounds of whole shiitake (*Lentinus edodes*) mushrooms. These four drying methods resulted in a significantly ($p < 0.05$) increase in the content of total free amino acids and the relative content of sulfur compounds of dried products. Microwave vacuum drying helped to maintain larger amounts of taste-active amino acids, and improved nutrient retention and color attributes. Furthermore, the uniform honeycomb network created by microwave vacuum drying along with a less collapsed structure of dried samples can be used to explain the observed high rehydration ratio. Therefore, microwave vacuum drying should be a potential method for obtaining high-quality dried mushrooms.

1. Introduction

People have used shiitake (*Lentinus edodes*) mushrooms, known in China as Xiang-gu, for thousands of years for both food and medicine. Shiitake, the second most cultivated edible mushroom in the world, represents about 25% of worldwide mushroom production. Shiitake production has increased faster than that of any other mushroom species (Jiang, Luo, & Ying, 2015). These high-quality mushrooms taste delicious and provide abundant nutrients. Shiitake contains 18 types of amino acids, providing nearly the ideal ratios of all essential amino acids needed for human nutrition (Turło et al., 2008). Important bioactive compounds in shiitake have anti-tumor and anti-cancer properties and can help lower blood pressure (Ampere, Delhaes, Soots, Bart, & Wallaert, 2012). Shiitake also provides lentinan and vitamin B_{12}, two components that can support the human immune response (Solanki et al., 2014; Zhang, Li, Wang, Zhang, & Cheung, 2011). In addition, these mushrooms contain large amounts of ergosterol and fungisterol. Ultraviolet rays in sunlight can convert these bioactive sterols to vitamin D, which enhances human resistance to the common cold and other disease. However, freshly harvested shiitake mushrooms start deteriorating immediately, causing nutrient loss. Therefore, fresh shiitake requires appropriate preservation methods to prolong shelf-life, maintain quality and reduce nutrient loss.

Drying effectively preserves shiitake mushrooms and prolongs their shelf life. Drying prevents the growth of spoilage microorganisms, slows enzyme activity, and slows many moisture mediated reactions (Garcia-Segovia, Andres-Bello, & Martinez-Monzo, 2011). In addition, people have especially prized the unique characteristics of dried mushrooms since ancient times. For example, dried shiitake mushrooms have greater amounts of some nutrients, such as vitamin D_2, than fresh mushrooms (Jasinghe & Perera, 2006). Dried shiitake mushrooms also have superior umami flavor, a flavor similar to meat, cheese, and other mushrooms. This flavor arises from the breakdown of proteins into amino acids during drying (Hiraide, Miyazaki, & Shibata, 2004). Therefore, using optimal drying methods will improve the quality of mushrooms.

Currently, low cost and easily controlled hot air drying (HAD) is widely used for preserving mushrooms. In addition, microwave drying (MD) and vacuum drying (VD) are being successfully applied to many foods (Chandrasekaran, Ramanathan, & Basak, 2013; Tian, Liang, Zeng, & Zheng, 2013). Each drying method has its own advantages and limitations. The final products obtained from these methods may vary in physicochemical or nutritional properties and microstructure. HAD may damage both nutritional quality and texture as well as cause discoloration during a long drying period (Alibas, 2010). MD distributes energy unevenly creating problems related to non-uniform heating (Chandrasekaran

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et al., 2013; Zhang, Tang, Mujumdar, & Wang, 2006). VD is especially suitable for heat sensitive products such as fruits with high sugar content and certain high value vegetables (Zhang et al., 2006). However, the low rate of heat transfer in VD causes an extended drying time. Therefore, new drying methods and dryers are needed to minimize drying time and improve product quality.

Microwave vacuum drying (MVD) provides a novel alternative which combines the advantages of both MD and VD. MVD improves drying rates, requires lower temperatures, and provides a more uniform and efficient distribution of energy than other drying methods (Wojdyo, Figiel, Lech, Nowicka, & Oszmianski, 2014). In addition, MVD may inhibit oxidation (Bai-Ngew, Therdthai, & Dhamvithee, 2011), and so highly preserve color (Yongsawatdigul & Gunasekaran, 1996) and nutrient components, including vitamin A, vitamin C, and thiamin (Erenturk, Gulaboglu, & Gultekin, 2005; Yongsawatdigul & Gunasekaran, 1996). Moreover, MVD provides dehydrated foods with an expanded porous cellular structure which develops under vacuum and internal vapor pressure conditions. This porous structure often results in a shorter rehydration time, more complete rehydration and greater water retention (Wojdyo et al., 2014; Yongsawatdigul & Gunasekaran, 1996). MVD has the potential to improve the quality and nutritional value of the dried products.

The objective of this study was to investigate the effects of MVD on several important quality parameters of shiitake mushrooms such as nutrient retention, rehydration rate, shrinkage, color, free amino acid and volatile compound content, microstructure, etc., when compared with HAD, VD, and MD.

2. Materials and methods

2.1. Materials

Fresh cultivated *shiitake* mushrooms graded according to uniform maturity and size were purchased from a mushroom farm in Gutian County, Fujian Province, China. All mushroom samples were transported to the laboratory and stored at a temperature of 4 ± 0.5 °C with 95% relative humidity in a refrigerator prior to experimentation. The average dimensions of the mushroom were 74.1 ± 2.7 mm in the major axis and 65.2 ± 3.1 mm in the minor axis of the cap. The length from the cap to stem averaged 78.8 ± 5.5 mm. The initial moisture content was 88.4 ± 1.4% (wet basis). All samples used for drying were purchased from the same batch.

2.2. Drying methods

2.2.1. MWV drying equipment and drying procedure

A multifunctional and programmable MWV dryer, with a maximum nominal power of 4.2 kW, and an operation frequency of 2450 MHz was used in this research. We designed this dryer and had it manufactured by Guangzhou Kailing Industrial Microwave Equipment Ltd. (Guangzhou, Guangdong, China) (Song, Zheng, & Zeng, 2009). The operational power is adjustable between 0 W and 4000 W. The dimensions of the microwave cavity were 500 × 500 × 500 mm. The maximum vacuum degree is −95 kPa (Tian et al., 2012). Samples were placed in thin layers on six plates; these were then placed in the microwave cavity and rotated at 1 rpm during microwaving of the material. The equipment was operated for 11 min at a microwave power density of 15 W/g and vacuum degree of −80 kPa. The drying process continued until the moisture content of shiitake mushrooms reached a dimensionless moisture ratio of 13% on wet basis.

2.2.2. Hot air drying

The samples were hot-air dried following the methods provided in Tian et al. (2012) using the same electric thermal dryer. The drying process lasted until the moisture content of shiitake mushrooms reached below 13% (wet basis).

2.2.3. Microwave drying

A laboratory microwave oven (M700, Guangdong Midea Microwave Oven Co. Ltd., Guangdong, China) with a maximum power output of 700 W and 2455 MHz was used. The dimensions of the microwave cavity were 105 × 140 × 445 mm. The samples were spread in a single layer on a glassy culture dish, and dried at 539 W of the microwave power. Drying lasted for 18 min until the sample moisture fell below13% (wet basis).

2.2.4. Vacuum drying

Vacuum drying was carried out in a vacuum drying oven with cavity dimension of 345 × 370 × 415 mm (DZF-6051, Shanghai CIMO Medical Instrumental Manufacturing Co., Ltd., Shanghai, China). The samples were spread in a single layer on a glassy culture dish, and dried in −90 kPa at 60 °C for 15 h when the sample moisture content reduced to 13% (wet basis).

2.3. Analysis methods

2.3.1. Moisture content

Moisture content of the shiitake mushroom samples was measured as described previously (Tian et al., 2012) using an oven and following the National Standard of China (GB/T8858-88).

2.3.2. Preparation and composition analysis of shiitake mushroom polysaccharides (SMPs)

SMPs were extracted with hot water, and then collected by ethanol with final concentration of 80% (v/v). The content of SMPs was determined using the phenol–sulfuric acid method using D-glucose as a standard (Wu et al., 2014). Protein content was measured using the Bradford protein assay kit (Bio-Rad Laboratories, Hercules, CA, USA). The uronic acid content was determined by 3-hydroxydiphenyl assay using glucuronic acid as a reference material (Wu et al., 2014).

2.3.3. Determination of vitamin B_{12} and D_2 contents

The total vitamin B_{12} compounds were extracted by boiling at pH 4.8 in the presence of 4.0×10^{-4}% KCN (Bito et al., 2014). Vitamin B_{12} was analyzed using high-performance liquid chromatography (HPLC) equipped with an octadecyl silica column (4 μm, 4.6 × 150 mm, Inertsil® ODS-3, GL Sciences Inc., Tokyo, Japan). Vitamin B_{12} was eluted with a mobile phase consisting of 25% methanol and 75% phosphate buffer (20 mM, pH 3.5) employed at a flow rate of 1 mL/min. The UV detection of the eluate was performed at 361 nm.

Vitamin D_2 was extracted and analyzed using the method of Jasinghe and Perera (2006) as modified by Wang, Zhang, and Mujumdar (2014). Vitamin D_2 content was determined using HPLC after saponification (methanolic KOH) and extraction of the composites three times with hexane/ethyl acetate. This was followed by concentration using a rotary evaporator. The mobile phase was methanol/H_2O (95:5, v/v) at a flow rate of 1.0 mL/min and UV detection was at 254 nm.

2.3.4. Shrinkage ratio

The shrinkage ratio was measured by a displacement method (Wang et al., 2014). The glass beads (0.1 mm, USA Scientific Inc., Orlando, FL, USA) were used as a replacement medium. The shrinkage ratio of dried lotus seeds was calculated as:

$$\text{Shrinkage ratio}\,(\%) = \frac{V_o - V_d}{V_o} \times 100 \quad (1)$$