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Drying of shiitake mushroom by combining freeze-drying and mid-infrared radiation

Hong-cai Wang[a], Min Zhang[a,b,*], Benu Adhikari[c]

[a] State Key Laboratory of Food Science and Technology, Jiangnan University, 214122 Wuxi, Jiangsu, China
[b] School of Food Science and Technology, Jiangnan University, 214122 Wuxi, Jiangsu, China
[c] School of Applied Sciences, RMIT University, City Campus, Melbourne, VIC 3001, Australia

ABSTRACT

Mid-infrared drying (MIRD) was applied before or after freeze-drying (FD) of shiitake mushroom to shorten the drying time, to enhance the rehydration, and to better preserve the aroma compounds and color. The effect of application of MIRD before freeze drying (MIRD–FD) and after freeze drying (FD–MIRD) on drying time, color, rehydration ratio, apparent density, microstructure and aroma compounds was measured, explained and compared with the effect of FD on these parameters. The results showed that the combination of FD (for 4 h) followed by MIRD saves 48% time compared to FD while keeping the product quality at an acceptable level. The MIRD–FD combination was found to be inferior compared to the FD–MIRD as the former tended to produce products with a collapsed surface layer and poor rehydration capability. The combination of MIRD with FD had a significant effect on aroma retention and caused an increase of sulfur compounds such as dimethyl, trisulfide and 1,2,4-trithiolane.

Keywords: Shiitake mushroom; Freeze-drying; Mid-infrared drying; Drying characteristics; Quality

1. Introduction

Freeze drying is widely used to obtain high quality dehydrated fruits and vegetables (Ratti, 2001). The solid state of water, low temperature and sublimation mode of moisture transport during freeze drying help protect the primary structure and shape of products and the resultant products often possess low bulk density, high porosity and better rehydration characteristics (Cui et al., 2008; Huang et al., 2011). However, freeze drying is slow and often low throughput process and also requires expensive equipment. Because of these reasons, its application is often restricted in producing high-value products (Wang et al., 2011). The low throughput and long residence time are due to very slow mass and heat transfer rates as the freeze drying process has to be maintained within triple point of water (Duan et al., 2007). Since freeze-drying is mass transfer controlled process, continuous heating does not accelerate the rate of water removal (George and Datta, 2002). Therefore, in the conventional freeze drying systems, it is difficult to significantly increase the rate of drying without compromising product quality. Hence, it would be of practical importance if an alternative freeze drying method with shorter drying time, lower energy consumption and producing desirable product quality is developed.

In recent years, freeze drying is combined with various other drying methods such as hot air, far-infrared radiation, microwave and microwave-vacuum. These hybrid drying methods are then used to dry fruits and vegetables to avoid disadvantages associated with non-hybrid or single drying method (Wang et al., 2011; Lin et al., 2007; Argyropoulos et al., 2011). Infrared (IR) heating offers many advantages over conventional hot-air drying; for instance, shorter drying time, higher energy efficiency and better product quality (Hebbar et al., 2004; Nimmol et al., 2007). When IR is applied to dry agricultural products, the IR radiation penetrates the product and is converted into heat by molecular vibration (Krishnamurthy et al., 2008). The IR radiation is absorbed by the materials without heating the surrounding air (Mongpraneet et al., 2002). The combination of infrared drying with other drying methods has proven beneficial; hence, a number of dryers have been developed by incorporating infrared radiators. It has been shown that the IR assisted freeze-drying improves drying efficiency, shortens drying time, and improves product quality (Lin et al., 2005;

* *Corresponding author at*: School of Food Science and Technology, Jiangnan University, 214122 Wuxi, Jiangsu Province, China. Tel.: +86 13606179162.
E-mail address: min@jiangnan.edu.cn (M. Zhang).

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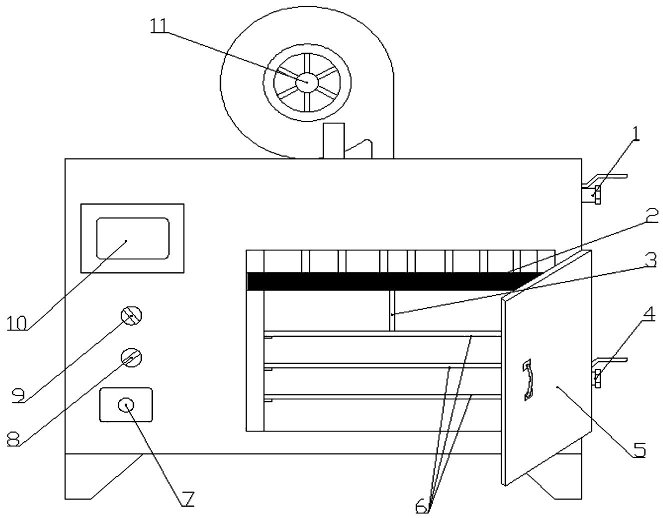

Fig. 1 – Schematic of mid-infrared assisted convection dryer. (1) Air intake; (2) radiation tube; (3) temperature sensor; (4) air outlet; (5) door; (6) load material plate; (7) air regulator; (8) switch (control blower); (9) switch (control heating tube); (10) display screen; (11) blower.

Chakraborty et al., 2011; Shih et al., 2008). Pan et al. (2008) used sequential infrared and freeze-drying (SIRFD) to produce high-quality dried fruits at reduced cost. The products dried using SIRFD had better color, higher crispness, higher shrinkage but poor rehydration propensity compared to those produced by using regular freeze-drying.

However, most of the IR-assisted freeze dryers use far-IR source with corresponding wave length in 3–1000 μm range (Lin et al., 2005; Chakraborty et al., 2011). There are no studies on the application of mid-infrared drying (MIRD) (corresponding to the wavelength ranges 1.4–3 μm) in combination with conventional freeze drying. It would be of practical interest to study the application IR-assisted freeze drying that uses MIRD on the microstructure and aroma of the vegetables such as mushroom. In this study, MIRD was combined with the conventional freeze drying to shorten the drying time and improve the physicochemical quality (color, rehydration ratio, apparent density, microstructure and aroma) of shiitake mushrooms.

2. Materials and methods

2.1. *Raw materials*

Freshly harvested shiitake mushrooms which were graded according to uniformity, maturity and size were purchased from local market (Wuxi, China) and stored in a refrigerator maintained at 4 °C. Mushroom samples were thoroughly washed and their stems were removed manually before drying. The average initial moisture content (MC) of these mushroom samples was 84 ± 1.7% (w/w), as determined using a hot air oven at 105 °C (AOAC, 2000).

2.2. *Experimental apparatus*

A conventional freeze dryer (YT2S-01) was purchased from Nanjing Yatai Microwave Power Technology Research Institute (Nanjing, China). Mushroom samples were dried by maintaining the pressure at 100 Pa and cold trap temperature between −35 °C and −40 °C. Mushroom samples dried in this way were taken as control.

A lab-scale mid-infrared dryer developed by Sentteck Co., Ltd. (Taizhou, China) was used. As shown in Fig. 1, the dryer was equipped with six changeable infrared quartz glass lamps (220 V, maximum power of per lamp = 450 W, radiation efficiency = 70–80%). These lamps were arranged in one row on the top surface of the drying chamber and transmitted infrared radiation in the range of medium to short wavelengths (wavelength zone = 2.3–3 μm). In order to improve the uniformity of radiation heating, all of the six IR lamps were switched on, and at a maximum power of 2.1 kW. Food samples were placed on the wire mesh tray (60 cm × 60 cm). Heating intensity was maintained at 5.8 kW/m^2. The distance from the IR heaters to the wire mesh trays was fixed at 14 cm. The temperature of the drying medium was measured continuously using type K (chromel–alumel) thermocouples and controlled by using a digital temperature controller. Type K thermocouples were fitted inside the drying chamber. The distance between the thermocouples and the infrared lamps was 10 cm. Our preliminary trials showed that when these mushrooms were dried at 70 °C they can be seriously deformed. Hence, the heating temperature of MIRD was chosen to be 60 °C.

2.3. *Experimental procedure*

The shiitake mushroom samples were dried by the freeze dryer (FD) by coupling with the mid-infrared (MIRD) device before and after the freeze drying step until the final moisture content (MC) was less than 12% (w/w).

In the FD process, the mushroom samples (100 ± 0.5 g) were spread uniformly in a single layer on a stainless steel tray and then frozen at −35 ± 2 °C for 5 h in an ultra-low-temperature freezer (U410, New Brunswick Scientific, New Brunswick, Canada). These frozen samples were then transferred to the FD chamber (cold trap temperature = −40 °C). The final heating temperature within the FD chamber was maintained at 50 °C. Drying continued until the sample MC was <12% (w/w).

In the mid-IR assisted freeze-drying (FD–MIRD), the MIRD step was applied after the freeze drying stage maintaining 60 °C until the moisture content was <12% (w/w). The freeze drying process occurs in two steps: ice sublimation followed by desorption (Shih et al., 2008). MIRD was used to replace the desorption process of FD in our research. This is because the desorption stage takes up nearly half of the total drying time. Based on preliminary trials, the heating temperature of FD was fixed at 50 °C. The mushroom samples dried by FD for 2 h (FD (2 h)–MIRD), 4 h (FD (4 h)–MIRD) and 6 h (FD (6 h)–MIRD) then dried by MIRD were chosen for further analysis.

The MIRD step (pre-dehydration step) was also applied before the freeze drying stage maintaining the temperature at 60 °C and then the samples were frozen at −35 °C before freeze-drying. The final moisture content of this sample was also brought down to <12% (w/w). The dried samples were packaged in aluminum foil bags for further quality analysis. Each experiment was carried out in triplicates.

2.4. *Analysis methods*

2.4.1. *Moisture content*

During drying, samples were removed at 1 h intervals and the sample mass was measured using an analytical balance to an accuracy of ±0.01 mg (JH2102, Shanghai Precision & Scientific Instrument Co., Ltd., Shanghai, China). The samples taken out for the moisture determination were discarded. Moisture content was calculated, as a function of time, using the difference in mass.