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FULL LENGTH ARTICLE

Drying characteristics of Chinese Yam (*Dioscorea opposita Thunb.*) by far-infrared radiation and heat pump

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Abstract Chinese Yam chips were dried using a heat pump (HP) dryer alone or in combination with far infrared radiation (FIR) at 500, 1000 and 2000 W (500 FIR, 1000 FIR, and 2000 FIR, respectively). The experimental results were presented in terms of the drying characteristics, and dried product qualities (shrinkage, color, texture, percentage of rehydration, and moisture content). Samples with initial moisture content of approximately 76% (w.b.) were dried to a final moisture content of $<17\%$ (w.b.) at the drying temperature of 50 °C and at an air flow rate of 1.0 m s^{-1} for all of the experiments. The data showed that FIR + HP drying increased the drying rate by reducing the drying time, and the resulted dried Chinese Yam chips generally had higher values of lightness and comparable values of redness and yellowness than the HP-treated samples. In the case of HP + 1000FIR, the dried Chinese Yam chips had lower shrinkage, improved rehydration ability, lower hardness and higher brittleness than those dried by HP, HP + 500FIR and HP + 2000FIR. It is worth noting that the total energy used for FIR-assisted drying processes decreased with the increase of FIR intensity. The present data suggest that HP + FIR drying is an effective and economical method for Chinese Yam chip drying, and HP + 1000FIR can obtain the best dried product.

1. Introduction

Yam is a popular food consumed in China, is are used as functional foods and herbal medicinal ingredients in traditional Chinese medicine (Yi et al., 2015; Ju et al., 2014; Chung et al., 2012; Lan et al., 2009; Wang et al., 2008). Chinese Yam (*Dioscorea opposita Thunb.*), specialty in Henan province, is normally consumed in fresh form. However, fresh Chinese Yam is difficult to store and easy to deteriorate during storage.

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In addition, Chinese Yam is a climacteric food and it is vulnerable to damage during transportation, preservation and marketing (Lin et al., 2007). After being wounded and contaminated, both qualitative and quantitative deteriorations occur through nutrition loss and physiological disorder (Kumar et al., 2014). So it is desired to develop a stable form dried Chinese Yam products.

Drying is largely utilized to stabilize the product by decreasing its water activity and moisture content, and reducing quality losses (Karunasena et al., 2015; Larrosa et al., 2015; Law et al., 2014). Compared to fresh products which can be only kept for a few days under ambient conditions, dried products can be stored for months or even years without appreciable loss of nutrients (Ortiz-García-Carrasco et al., 2015; García-Alvarado et al., 2014). Besides, drying can also create new product-forms, which add value to raw materials.

Chinese Yam chips can be produced by various conventional drying methods, and the most common technique is hot air drying which is a simple process. However, due to the low thermal conductivity and internal resistance to moisture transfer of food materials, this method always leads to low efficiency of heat transfer, and the quality of the dried product is generally reduced and often unsatisfactory.

Heat pump (HP) drying can improve energy efficiency and independently control the drying temperature and air humidity (Minea, 2013; Yang et al., 2013; Zielinska et al., 2013; Artnaseaw et al., 2010), which is especially suitable for temperature sensitive vegetables and fruits as drying can occur at low temperature (Fan et al., 2014; Hossain et al., 2013; Hii et al., 2012). However, heat pump drying is a rather slow drying process. In order to reduce the drying time, it is necessary to add an extra source of energy to the system. Far-infrared radiation (FIR) has received much attention recently, which is one possible means for the above purpose (Park et al., 2009). During FIR drying, the energy in the form of electromagnetic wave is absorbed directly by the sample without any loss to the environment leading to considerable energy savings (Lee and Jeon, 2010). In addition, infrared radiation technology for dehydrating foods could reduce drying time, maintain uniform temperature in the product, and provide better-quality finished products (Krishnamurthy et al., 2007). This drying method is especially suitable for thin layers of material with large surface exposed to radiation (Park et al., 2009). Some studies have been reported in the literature on the influence of the far infrared radiation combined with low-pressure superheated steam drying (Leonard et al., 2008; Nimmol et al., 2007), freeze drying (Senevirathne et al., 2010), vacuum drying (Swasdisevi et al., 2009), and convective drying (Wanyo et al., 2011; Jaturonglumlert and Kiatsiriroat, 2010). On the drying properties of Chinese Yam, there are few articles focusing on the combination of far infrared radiation and heat pump drying. The characteristics of longan (Nathakaranakule et al., 2010), squid fillets (Deng et al., 2011), and banana chips (Song, 2013) dried using a combination of heat pump drying and far infrared radiation were reported in recent years. To the best of our knowledge, there is little study on the effects of FIR assisted HP drying on the qualities of Chinese Yam chips.

To attain the advantages of the above-mentioned drying techniques, the combination of heat pump and far-infrared radiation drying is proposed as a drying technology for Chinese Yam chips in this study. The effects of various radiation powers on the drying characteristics of Chinese Yam chips as well as the energy consumption of the process were investigated and discussed.

2. Materials and methods

2.1. Materials preparation

Fresh Chinese Yams (*Dioscorea opposita Thunb.*) purchased from a local market in Zhengzhou, China, were brought to Food Engineering Laboratory and stored at 4 °C. The yams with similar size were selected according to the required cylindrical form. Before each drying experiment, Chinese Yams were peeled, and both ends were removed and discarded. Thereafter, the fruits were sliced to 3 mm thickness pieces using a cutting machine immediately, and dipped into 0.005 mol L^{-1} citric acid solution for 10 min. After draining the excess water, the Chinese Yam chips were placed on the tray dryer in a single layer.

2.2. Experimental setup and methods

The self-made experimental drying apparatus combined heat pump dryer with FIR is shown in Fig. 1. The dryer consists of a stainless steel drying chamber with inner dimensions of 30 × 60 × 50 cm, a 1.5 kW heat pump to supply heat to the drying chamber, and a centrifugal fan driven by 1.0 kW motor. Six infrared heaters (each with a maximum power of 500 W) were installed into the drying chamber, three FIR heaters at the top and three at the bottom of the drying chamber. Two wire mesh trays were placed midway between, and parallel to the top and bottom heaters. The distance between FIR heaters and the trays was fixed at 15 cm. The dryer also includes a 2.0 kW capacity evaporator, a condensing unit, which consists of a 0.6 kW compressor and a 3.0 kW capacity condenser. We assume that the samples experienced the same heat transfer, because the distance between the FIR-heaters and samples was the same and the samples were placed close to one another. The thermal inertia of the IR lamps was assumed to

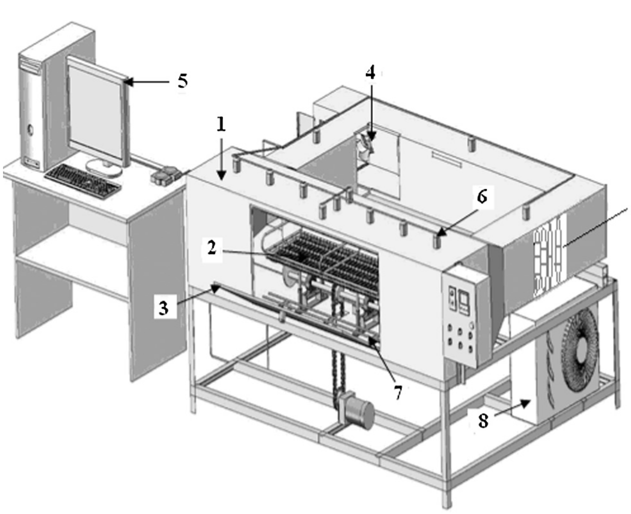

Figure 1 Experimental drying apparatus. 1. Drying chamber, 2. sample tray, 3. cover, 4. fan, 5. data logger, 6. transducer, 7. far infrared heater, 8. condenser, and 9. evaporator.

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