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Heat and moisture transport behaviour and quality of chopped garlic undergoing different drying methods

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ABSTRACT

A far-infrared radiation-assisted heat pump (HP-FIR), which is a novel drying method, was used for drying chopped garlic and compared with conventional hot-air (HA) drying. The drying characteristics and the qualities of the dried chopped garlic in terms of the allicin content, volatile oil content and colour were investigated. HA and heat pump (HP) drying were carried out at a temperature of 50 °C. The far-infrared radiation (FIR) power levels used in combination with HP drying were 250, 350 and 450 W. A coupled heat and mass transfer model was developed to estimate the effective moisture diffusivity (D_{eff}) and to predict the evolution of the moisture content and internal temperature of chopped garlic. The experimental results showed that an increase in the FIR power resulted in a faster decrease in the moisture content and a shorter drying time. The amounts of allicin in samples dried by HP-FIR at different FIR powers were not significantly different; their percentage losses were about 20% higher than those obtained from HA or HP drying. However, the volatile oil contents in all dried samples were similar to those of fresh samples. HP drying provided garlic powder with the brightest colour as manifested by the highest values of *L* and the hue angle. The values of *L* and the hue angle had a decreasing trend when the FIR power increased. In addition to quality issues, the developed model could estimate the D_{eff} of chopped garlic rather well. The D_{eff} value was in the range $0.41–1.43 \times 10^{-10}$ m^2/s at the internal product temperature range from 50 to 62 °C. The predicted moisture content and internal temperature of chopped garlic agreed quite well with the experimental data.

1. Introduction

Garlic (*Allium sativum* L.) has been used not only as a spice and a flavouring agent for food but also as a supplement for medicinal effects, such as antimicrobial, antithrombotic, antioxidant and anticancer activities (Lawson and Wang, 2001). The medicinal properties of garlic are attributed to allicin and its degradation products (Block, 1992; Chung, 2006; Yu et al., 1993). Allicin is not present in intact garlic, but it is rapidly produced when raw garlic is crushed or chopped. After crushing, the allinase enzyme comes into contact with alliin and converts alliin into allicin and pyruvic acid. Allicin is unstable in the presence of heat or organic solvents. It readily degrades to a variety of degradation products, such as allylsulfides, vinyldithins and ajoenes (Lawson et al., 1991a).

Garlic powder, one of the most popular commercial garlic products, can be produced by drying garlic cloves or slices. The dried samples are then pulverized into powder. The quality of garlic powder is standardized on allicin (Lawson et al., 2001). However, the amount of allicin varies greatly among different brands (Lawson et al., 1991a). This is due to the different processing procedures, such as sample preparation, drying method and drying conditions (Fujisawa et al., 2008). It is well known that freeze drying can provide products with excellent quality. Ratti et al. (2007) reported that freeze-dried garlic slices had the same allicin content as fresh garlic. However, this drying method is rather expensive.

Hot-air (HA) drying is another method commonly used for drying garlic slices (Cui et al., 2003; Ratti et al., 2007). This drying method is much less expensive than freeze drying. Ratti et al. (2007) reported that the allicin content in garlic slices dried by HA at 40–50 °C was similar to that of freeze-dried garlic slices. However, not much allicin was produced in fresh garlic slices since allinase did not come into contact with alliin as much as with crushed or chopped garlic. The high potential to produce allicin

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in garlic slices dried by HA at 40 and 50 °C could be due to maintaining allinase activity and alliin (Ratti et al., 2007). The allinase is denatured at 42 °C and is inactivated at temperatures above 60 °C while the alliin breaks down at temperatures above 100 °C (Méndez Lagunas and Castaigne, 2008). Thus, the allicin, which is the result of the alliin–allinase reaction, could be produced. However, drying at low temperature is rather costly due to the long drying time, especially when drying is performed in the rainy season. High temperature drying can shorten the drying time. However, it may inactivate the allinase, and thus the allinase can no longer hydrolyze alliin to allicin (Li et al., 2007). To avoid the inactivation of enzymes and to improve the drying rate, a reduction in the sample size before drying may be a possible way to shorten the drying time since the diffusion distance is shorter and the surface area of the sample exposed to hot air is increased. The size of garlic is greatly reduced by chopping.

Much allicin is produced during chopping. However, allicin may be lost or degrade to other compounds during the processing steps, including drying. This study tried to maintain the allicin in the chopped garlic. Heat pump (HP) drying has been proposed as an attractive method for drying heat-sensitive food products where low temperature and low humidity are required to preserve or improve product quality (Chou and Chua, 2001). The HP recovers the sensible and latent heats by condensation of moisture from the drying air (Islam and Mujumdar, 2004). At low temperature, HP drying has the potential to operate more efficiently than HA drying (Alves-Filho and Strommen, 1996). Boonnattakorn et al. (2004) studied the drying characteristics and quality of garlic slices dried by HA and HP. It was found that HP drying provided a shorter drying time and retained higher amounts of active ingredients for both allicin and total thiosulfinate contents. The colour of garlic slices dried by HP was closer to fresh garlic than that dried by HA. Phoungchandang et al. (2003) investigated the effects of HA and HP drying on eugenol and methyl eugenol in holy basil (*Ocimum sanctum* L.). The results indicated that HP drying was able to retain higher levels of eugenol and methyl eugenol than HA drying.

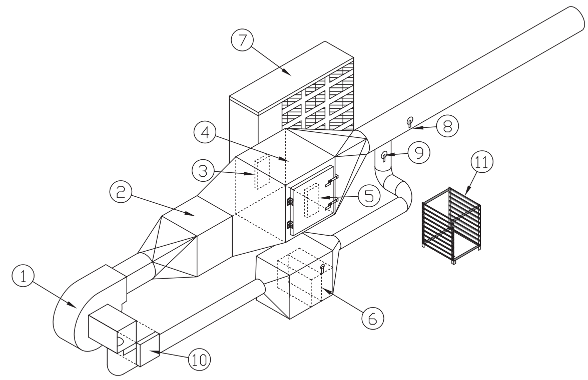
Although the quality of these products has been proven to be excellent with the use of HP drying, it takes quite a long drying time which may cause a higher loss of volatile compounds (Sharma and Prasad, 2001). To overcome this problem, far-infrared radiation (FIR) has been combined with HP drying. Nathakaranakule et al. (2010) combined FIR with an HP (HP-FIR) for drying longan. They reported that the HP-FIR could reduce the drying time and also improve the dried product quality, with regards to shrinkage, rehydration and texture. This indicated that FIR has potential to be combined with HP drying. Up until now, there has been no information on the quality of garlic dried by HP-FIR.

Therefore, the objective of this work was to study the effect of drying methods, i.e., HA, HP and HP-FIR drying on the drying characteristics and the qualities of dried chopped garlic in terms of the allicin content, volatile oil content and colour. In addition, a coupled heat and mass transfer model was developed to determine the effective moisture diffusivity and also to predict the change in the moisture content and internal temperature of chopped garlic during drying.

2. Materials and methods

2.1. Experimental set-up

A cabinet dryer as depicted in Fig. 1 was used in this study. It can be operated in multimodes including HA drying, HP drying and HP-FIR drying. The drying system consists of a forward-curved-blade centrifugal fan driven by a 2.2 kW motor, electrical heaters rated at 9 kW, a drying chamber with dimensions of



(1) Fan; (2) Heaters; (3&5) FIR heaters; (4) Drying chamber; (6) Evaporator; (7) Condenser; (8&9) Butterfly valves; (10) Cover; (11) Tray

Fig. 1. Schematic diagram of a cabinet dryer.

$0.52 \times 0.52 \times 0.52$ m, two 650 W far-infrared ceramic heaters (one at the front and another one at the back of the drying chamber), perforated trays sized 0.28×0.33 m and a heat pump unit which comprises a 2 kW capacity evaporator, a 3.5 kW capacity condenser, a 0.65 kW compressor and an expansion valve.

For HA drying, air was heated by electrical heaters. The air temperature was controlled by a Proportional–Integral–Derivative (PID) controller. The heated air was then delivered to the drying chamber where the sample trays were placed in parallel with the air flow. Eighty percent of exhaust air was recycled by adjusting the No. 8 butterfly valve (see Fig. 1). Air velocity was controlled by controlling the rotation speed of the motor using a frequency inverter. In the case of HP drying, the dryer was changed to a closed system by closing the No. 8 butterfly valve and attaching a No. 10 cover. Humid air at the dryer exhaust was passed through the evaporator. The condensation of water vapour in the exhaust air occurred at the evaporator when its temperature was below the dew point. Thus, the air relative humidity was reduced and the resulting dry air was then delivered to the drying chamber. In the case of HP-FIR drying, FIR assisted the HP drying. Two FIR heaters were operated at 220 V and at a maximum power of 650 W. The FIR intensity could be adjusted by regulating the FIR power using a voltage regulator. The FIR power levels used in this study were 250, 350 and 450 W. The temperatures of the FIR heaters were approximately 270, 330 and 385 °C when the FIR power levels were 250, 350 and 450 W, respectively. The mean distance between the FIR heaters and the sample surface was approximately 0.22 m.

2.2. Sample preparation

Fresh garlic bulbs were purchased from a wholesale market in Pathum Thani, Thailand. Their moisture content varied from 1.8 to 2 kg/kg dry matter. The garlic bulbs were manually cracked into cloves. The cloves were manually peeled and then sliced into 2 mm thickness with a slicing machine. The slices were manually chopped into small pieces; the equivalent spherical diameter of the chopped garlic was approximately 2 mm. A sample of 600 g of chopped garlic was prepared in each experimental run. The time required for slicing and chopping was about 30 min. And during these preparation steps, allicin was produced due to the fact that the allinase came into contact with alliin and converted the alliin into allicin and pyruvic acid. Lawson and Wang (2001) reported that allicin formation is completed within 6 s after cloves are crushed or chewed.