PORE SIZE DISTRIBUTION OF EGGPLANTS DRIED BY DIFFERENT DRYING METHODS

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Abstract

The main objective of this study is to investigate the effects of hot air drying and microwave-infrared combination drying on porous structure of eggplants. Hot air drying was performed in a tray dryer at 50°C with an air velocity of 1.5 m s^{-1}. In microwave-infrared combination oven, different microwave powers (30%, 40% and 50%) were combined with different infrared powers (10%, 20%). During drying process, initial moisture content decreased from 14 kg water kg^{-1} dry solid to approximately 0.13 kg water kg^{-1} dry solid for eggplants. Pore size distributions of dried samples were analyzed with mercury porosimetry. Pores in different samples were characterized by cumulative intrusion curves which showed total volume of mercury intruded the poresin any size range and the threshold diameter. Cumulative intrusion curves had a sharp rise that indicated existence of macro pores on the surface. Unlike microwave–infrared combination dried eggplants, hot air dried eggplants did not have pores above 200 µm size. Threshold diameter of eggplants dried in microwave-infrared combination oven were in the range of 48.86–73.42 µm which were greater than that of hot air dried eggplant, 42.47 µm. Microwave-infrared combination drying provided more porous structure than hot air dried ones due to higher internal pressure. As infrared and microwave power increased, threshold diameter increased and eggplants with more porous structure were obtained.

Keywords: microwave, infrared, drying, eggplant, porosity.

Introduction

Eggplant (*Solanum melongena* L.) is an important market vegetable of Asian and Mediterranean countries. It contains a variety of phytochemicals such as phenolics and flavonoids (Akanitapichat et al., 2010). It is ranked amongst the top ten vegetables in terms of antioxidant capacity due to the phenolic constituents (Cao et al., 1996). However, due to the higher moisture content, they have limited shelf life. In order to extend their shelf lives, it is common to dry eggplants. Dried eggplants can be used as an ingredient in different kinds of meals, instant soups and sauces.

Drying is a removal of moisture from the food materials to prevent the growth and reproduction of spoilage microorganisms and to slow down the action of enzymes and minimize many of the moisture mediated deteriorative reactions (Wu et al., 2007). Texture, appearance, colour, flavor, taste and nutritional value are affected from drying process conditions. Therefore, deciding suitable drying system is very important for food products. Although hot air drying method is used most commonly in industry, during hot air drying, food is exposed to heat for longer time. It causes problems related to quality parameters such as unacceptable color, flavor, texture, sensory characteristics, loss of nutrients, shrinkage, reduction in bulk density and rehydration capacity (Maskan, 2001). In order to eliminate these problems, microwave heating can be used for drying of foods. It provides high internal pressure that causes shorter drying time and more porous structure. In recent years, microwave drying has been used in drying of carrots (Arikan., 2012), potatos (Wang et al., 2004) andapples (Askari et al., 2006).However, due to the lower surrounding temperature, microwave heating causes condensation at the food surface. In order to eliminate this problem, Datta, Ni (2002) recommended the combination of infrared heating with microwave heating to dry food products. Infrared heating increases the surface temperature so excess surface moisture evaporates. Therefore, microwave-infrared combination drying has time saving advantage without the formation of sogginess.However, in literature, there are limited studies on microwave-infrared combination drying (Sumnu et al., 2005; Tireki et al., 2006). Sumnu et al. (2005) dried carrot by using microwave-infrared combination and hot air drying. It was stated that by using microwave-infrared combination drying, drying time was reduced to 98% of hot air drying time. Moreover, in the case of microwave-infrared combination drying, less color change and higher rehydration capacity of carrots were obtained as compared to conventional drying. Tireki et al. (2006) produced bread crumbs by conventional and microwave-infrared combination drying and it was stated that by using microwave-infrared combination drying, drying time was reduced to 96.8–98.6% of conventional drying.

One of the most important parameters that shows the effect of drying process on the quality of food is pore structure. More porous structure is an indication of less damage during drying. However, there is limited information about pore structure of dried fruits and vegetables. Schiffmann (1986) and Krokida, Maroulis (1999) analyzed porosity of microwave-dried apples, bananas, carrots and potatoes and concluded that microwave drying increased product porosity. Russo (2013) studied the effect of air temperature on microstructure of hot air dried eggplants and stated thatthe porosity increased with the air temperature.However, the effect of microwave-infrared combination drying on pore structure of eggplants has not been studied yet. Therefore, the objective of this study was to compare the effects of hot-air convectional drying and microwave-infrared combination drying on pore structure of eggplants.

Materials and Methods

Material

Eggplants (*Solanum melongena* L.) used in this study were obtained from the local market and stored in a refrigerator at 4 °C. Prior to drying, samples were washed and cut into slices, of a thickness 5 mm using a kitchen slicer. Diameters of the eggplants were 5.0±0.5 cm and the weight of each sample was 7.0±0.5 g. The initial moisture content of eggplant was found to be 14 ±0.314 kg water kg^{-1} dry solid by using moisture analyzer (MX-50 AND Moisture Analyzer, Tokyo, Japan).

Drying method

Hot air drying was performed in a tray dryer (Armfield Limited, D 27412, Ringwood Hampshire, England). The size of the tray was 18×30 cm^2. Drying experiments were carried out at 50 °C with an air velocity of 1.5 m s^{-1} until a moisture content of 0.13±0.002 kg water kg^{-1} dry solid was reached in almost 4 hour. In each experiment, 100–115 g of eggplants were dried and weight of samples was recorded at every 1 hour interval. That is, 1.85–2.13 kg eggplants were placed on one m^2 of tray for drying.

Microwave-infrared combination drying experiments were performed in microwave-infrared combination oven (Advantium oven™, General Electric Company, Louisville, KY, USA). In the experiments, powers of halogen lamps two at the top and one at the bottom which are sources of infrared power were 1500 W. Combinations of different microwave power levels (30%, 40% and 50%) and infrared powers (10% and 20%) were used in drying of eggplants. The power of the oven was determined as 630 W by using IMPI 2 liter test (Buffler, 1993). For both cases, 100–115 g of eggplant was dried until a final moisture content of approximately 0.13 kg water kg^{-1} dry solid was achieved in almost between 19–30 minutes. In every 2 minutes, weight of the samples was recorded by a digital balance (ARD-110 - Single Unit, China).

Pore-size distribution

Pore size distribution was determined by using mercury porosimeter (Poremaster 60, Quantichrome Corp., Boynton Beach, Florida, USA). About 0.5 g of dried eggplants was used for each experiment. Measurements were done at pressure range of 0–50 psia, and for calculations, surface tension and contact angle of mercury was taken as 480 erg cm^{-2} and mercury contact angle as 140°, respectively. Relation between applied pressure (P) and pore size was expressed by Washburn equation (Russo et al., 2013) which describes a linear relationship between the size of an intrudable circular pore and the applied mercury pressure in the mercury porosimeter.

$$P.r = -2\gamma\cos\theta \qquad (1)$$

where r is the pore radius (µm), γ is the Hg surface tension (N/m), θ is the contact angle (°) and P is the absolute applied pressure (N).

Results and Discussion

The plot of cumulative volume of mercury intruded versus pore size or versus pressure is called as cumulative intrusion curve. From the cumulative intrusion curve, the total volume of mercury intruded the pore volume in any pore size range and the threshold diameter (the diameter above which comparatively low mercury intruded) can be determined (Aligizaki, 2006).

The cumulative volumes of mercury intruded as a function of pore size and pressure of dried eggplants using different combination of microwave and infrared powers were indicated through Figures 1 to 4. Figure 5 was given to show the cumulative intrusion curve of eggplant dried by hot air.

Initially, there was a sharp increase in intrusion volume and then a relatively constant region with increasing pressure in all graphs. Initial step rise indicated that there were macro pores on the surface and the same sized pores existed predominantly. This can be the result of less collapse in the structure due to short drying time. A gradual rise on the slope can be an indication of decreasing pore size through the sample (Rahman et al., 2002).

Pore size ranges for eggplants dried at 10% infrared and 30% microwave power, 20% infrared and 30% microwave power, 10% infrared and 50% microwave power and 20% infrared & 50% microwave power combinations were from 227.4 to 4.39 µm; from 201.3 to 4.28 µm; from 235.3 to 4.27 µm; 210.6 to 4.27 µm, respectively (Figures 1–4). When hot air dried eggplants were compared with microwave-infrared combination dried eggplants, pore size range of hot air dried eggplants was narrower. Unlike microwave-infrared combination dried eggplants, hot air dried eggplants did not have pores above 200 µm size (Figure 5).

Threshold pore size was the pore diameter where the vertical line was observed and the diameter above comparatively low mercury intruded. Threshold pore size of hot air dried eggplants was 42.47 µm which was lower than the threshold pore size of eggplants dried with microwave-infrared combination. This result could be related to higher shrinkage and lower porosity due to higher drying time of conventionally dried eggplants.

As infrared and microwave power increased, threshold pore size increased. Threshold pore sizes were 48.86 µm and 55.40µm for 10% infrared and 30% microwave power combination and 20% infrared and 30% microwave power combination, respectively. Also, the threshold pore sizes were 64.89 µm and 73.42 µm for 10% infrared and 50% microwave power combination and 20% infrared and 50% microwave power combinations, respectively. This can be attributed to the reduction of shrinkage due to the increased microwave and infrared power. Similar pattern was observed for spouted bed drying of wheat (Kahyaoglu, 2009). As the temperature increased, shrinkage was enhanced so threshold pore size decreased slightly.

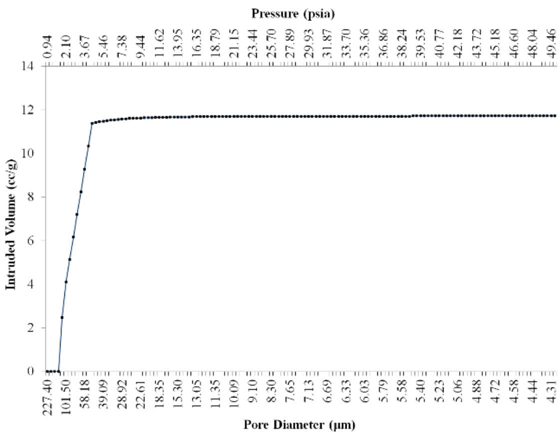

Figure 1. Cumulative intrusion curve for eggplants dried in microwave-infrared combination oven at 10% infrared and 30% microwave powers

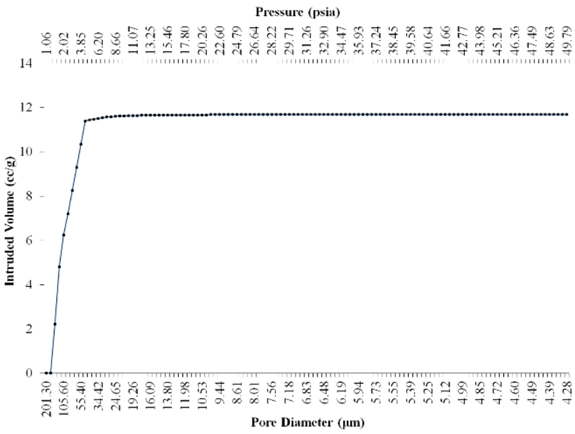

Figure 2. Cumulative intrusion curve for eggplants dried in microwave-infrared combination oven at 20% infrared and 30% microwave powers

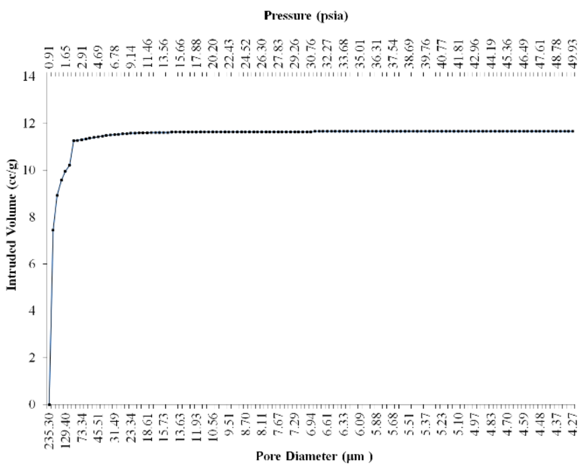

Figure 3. Cumulative intrusion curve for eggplants dried in microwave-infrared combination oven at 10% infrared and 50% microwave powers

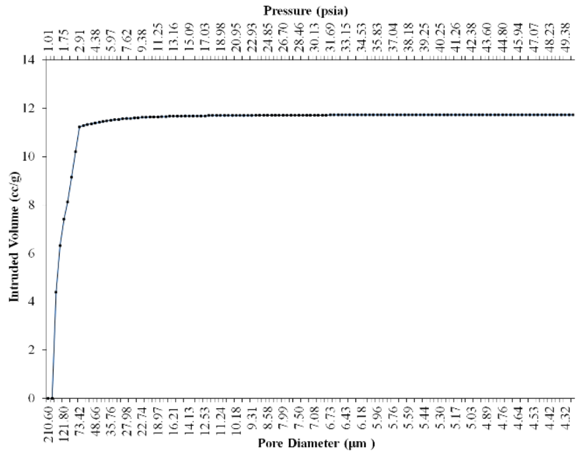

Figure 4. Cumulative intrusion curve for eggplants dried in microwave-infrared combination oven at 20% infrared and 50% microwave powers

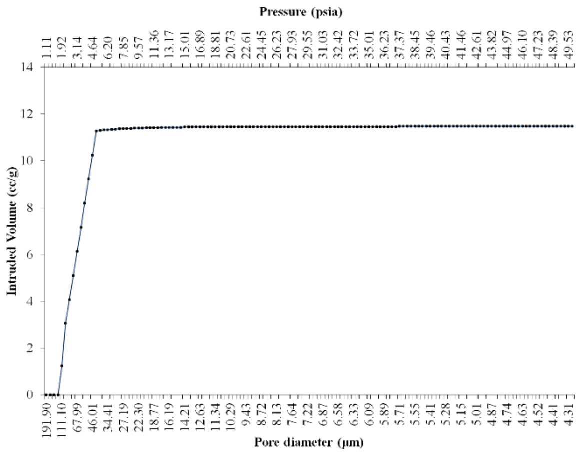

Figure 5. Cumulative intrusion curve for eggplants dried in hot air dryer

Conclusions

According to cumulative intrusion curves, hot air dried eggplants had less porous structure than the ones dried in microwave-infrared combination oven. In addition, increasing microwave and infrared power resulted in more porous structure. The optimum drying condition is 20% infrared power and 50 microwave power combination that provides more porous structure. Thus, microwave-infrared combination drying can be recommended to be used for drying of eggplants.

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