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Drying Characteristics of Radishes using Far Infrared Ray Dryer

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Abstract

Purpose: The purpose of this study was to establish conditions to dry a radish by examining the drying and quality characteristics depending on the air temperature and velocity of a far infrared conveyor dryer. **Methods:** A sample of weighing 6 kg was dried until the moisture content reached 15±0.5% (w.b.). Four temperatures (50, 60, 70, and 80°C) and three air velocity levels (0.4, 0.6, and 0.8 m/s) were employed as the drying factors. **Results:** The drying rate increased with the increase in the temperature and air velocity but decreased with time. However, the drying rate was influenced by temperature rather than velocity. At a temperature 50°C with a air velocity of 0.4 m/s, it took 350 min for the radish to dry which was the longest drying time; 80°C with a air velocity of 0.8m/s, it took 180 min for the radish to dry, which was the shortest drying time. △E (the color difference value) increased with the increase in temperature and air velocity. The browning and rehydration ratio increased as the temperature rose. Energy consumption decreased with the increased temperature and air velocity. **Conclusions:** Based on the results of this study, the best drying conditions for the radish were determined to be a temperature of 70°C with an air velocity of 0.8 m/s.

Keywords: Browning, Color difference, Far infrared drying, Radish, Rehydration ratio

Introduction

Radishes (*Raphanus sativus L.*) are annual or biennial brassicaceous crops that are, extensively consumed in Korea along with Napa cabbages (Cho et al., 2009). Radish juice contains enzymes such as amylase, amidase, and glycosidase, which have an excellent effect on digestion (You, 1993).

Production of radish in the country has reached 1 million tons since 2000, and it is consumed mostly in winter along with Napa cabbage. Radishes are now becoming available year-round due to the development of vegetable cultivation techniques. However, an oversupply caused by the increase in cultivated areas during a specific season or year has caused the price of radishes to drop, which has resulted in economic disadvantages such as the voluntary reduction of shipments and disposals. Therefore, a drying process for the surplus radishes is needed to maintain both quality and safety.

Radishes can be dried by sun or hot air. In the sun, they need a long period of drying time because of the influence of the weather, and also, the moisture content cannot be controlled. Moreover, the vegetables tend to be contaminated by dust, bacteria, pests, and insects during the drying process; therefore, it is difficult to obtain a high-quality product. On the contrary, it takes less time to dry radishes using hot air compared with drying them in the sun, but quality degradation such as shrinkage, surface hardening, low resilience, discoloration, and nutrient destruction occurs during the drying process (Lee et al., 2006). Thus, studies on new drying methods for radishes to reduce energy consumption and maintain high quality are needed.

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Most studies on radishes have analyzed the physico-chemical properties of fresh radishes (Ryu et al., 2000), the enzymatic and functional properties extracted from radishes (Kim & Lee., 1989), and the quality characteristics of hot-air-dried radish leaves (Ku et al., 2006). Far infrared rays can be used in the drying of food and agricultural products to reduce energy consumption, shorten drying time, and ensure uniformity. Therefore, the drying method using far infrared rays is necessary to produce high-quality dried products and strengthen their competitiveness in the agricultural industry. However, enough research on drying radishes using far infrared rays has not been conducted.

For this reason, this study aimed to establish the appropriate drying conditions for radish by examining the drying and quality characteristics of radishes at various air temperatures and velocities under a far infrared conveyor dryer.

Materials and methods

Sample

Radishes grown on Jeju Island were purchased at a market in Cheong-ju, and their initial moisture content was 94% (w.b.). The radishes were washed and shredded to 8.76 × 8.47 × 50 mm (width × height × length) with a vegetable shredder.

Experimental device

A far infrared conveyor dryer was used for this study, as depicted by Figure 1. The dimensions of the dryer were 5500×1800×900 mm (length × height × width), and it was composed of far infrared heaters (MEP-550, Restoration, Korea); drying chamber 5430 × 90 × 620 mm (length × height × width); belt conveyors (five layers); blast pans (DTB-402, Dongkun, Korea); and a control panel that can control the temperature of the far infrared heater, the belt speed, and the air velocity.

Methods

A sample weighing 6 kg was used for each drying condition and was dried until the final moisture content reached 15 ± 0.5% (w.b.). Based on the results of our preliminary experiments, the far infrared drying test was conducted at four temperatures (50, 60, 70, and 80°C), and three air velocity levels (0.4, 0.6, and 0.8 m/s) were employed as drying factors. The radishes were covered evenly on the conveyer belt with a depth of 2-3 cm. To measure the moisture content of the radishes during the drying process, sample trays containing the samples were placed on the conveyer belt. The sample trays were taken out of the drying chamber, weighed on a digital top pan balance, and placed back into the drying chamber at 30- min intervals during the drying process (Ning et al., 2013).

Measured items

Moisture content

The shredded radishes were measured by 10±0.5 g with an electronic scale (HF-200GD, AND, Japan) and dried in an oven (WFO-600ND, TOKYO RIKAKAI Co., Japan) at 105°C for 24 h. The moisture content was represented by

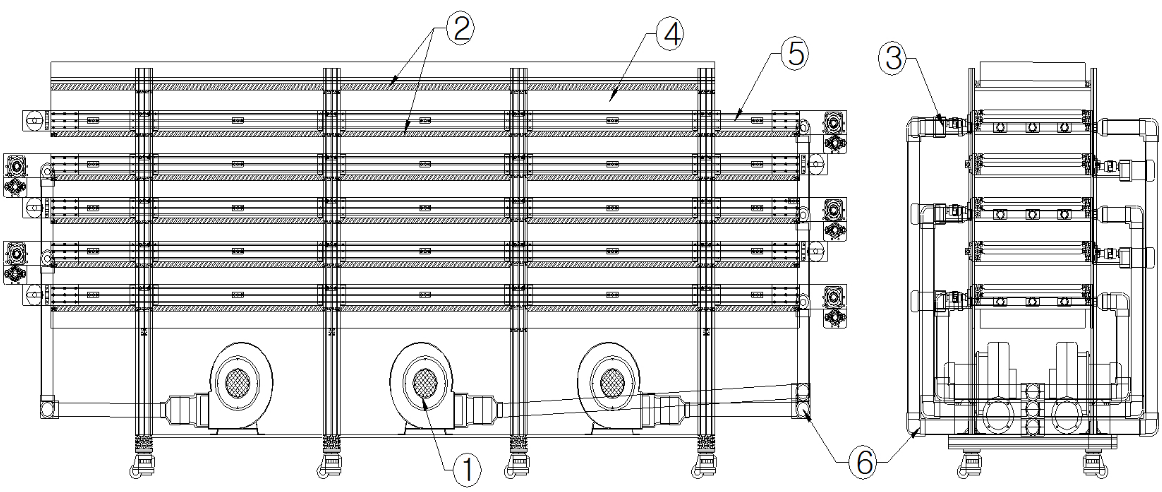

Figure 1. Schematic diagram of far infrared conveyor dryer.

the wet basis moisture content after calculating the weight ratio.

Color

Color changes were measured for ten samples using a colorimeter (JX-777, C.T.S., Japan). The radish sample (20 g) completely covered the lens surface. The sample was classified as L (black [0] to light [100]), a (red [60] to green [-60]), and b (yellow [60] to blue [-60]), and the L, a, and b values of the white calibration plate were 98.81, 0.08, and 0.06, respectively. The color difference, ΔE reflecting the color changes, was calculated with Equation (1).

$$\triangle E = \sqrt{\triangle L^2 + \triangle a^2 + \triangle b^2} \quad (1)$$

where, ΔE is the color difference of the radish after drying; ΔL is the brightness difference of the radish before and after drying; Δa is the redness difference of the radish before and after drying; and Δb: the yellowness difference of the radish before and after drying.

Rehydration ratio

A certain amount of the dried radish was soaked in distilled water at 100°C for 40 ~ 60 min and then weighed. The rehydration ratio of the dried radish was calculated using Equation (2). The temperature was maintained by immersing the beaker in a water bath at 100°C, and the surface water was removed using a Büchner funnel.

$$RR = \frac{W_f - W_i}{m_d} \quad (2)$$

Where, RR is the rehydration ratio (g); W_f is the sample weight after rehydration (g); W_i is sample weight before rehydration (g); and m_d is the dry weight of the sample before rehydration (g).

Browning

A ground radish (1.3 g) was suspended in a mixture (40 mL of distilled water and 10 mL of 10% trichloroacetic acid) and was allowed to stand at room temperature for 2 h. The mixture was poured through filter paper (Whatman No. 1), and the browning was determined by the absorbance value by measuring the absorbance at 420 nm using a spectrophotometer (CE393, Cecil Co., USA).

Energy consumption

The energy consumption of the far infrared dryer was measured using an integrating wattmeter (Energy Monitor 2720, SOAR, Italy), and was then, converted to the energy removal 1 kg of water.

Results and Discussion

Drying rate

The moisture content of the radish was affected by the drying temperature and air velocity (Figure 2). The drying condition of 80°C at a velocity 0.6 m/s and 80°C at a velocity 0.8 m/s showed the fastest drying rate of 180 min, and the drying condition of 50°C at a velocity 0.4 m/s showed the slowest drying rate of 350 min. Therefore, the drying rate increased with the increase temperature and air velocity.

The drying times with an air velocity of 0.4 m/s were 350, 280, 230, and 210 min at a temperature of 50, 60, 70, and 80°C, respectively. The drying time with an air velocities of 0.6 m/s took 320, 270, 220, and 180 min at four temperatures (50, 60, 70, and 80°C), respectively. With and

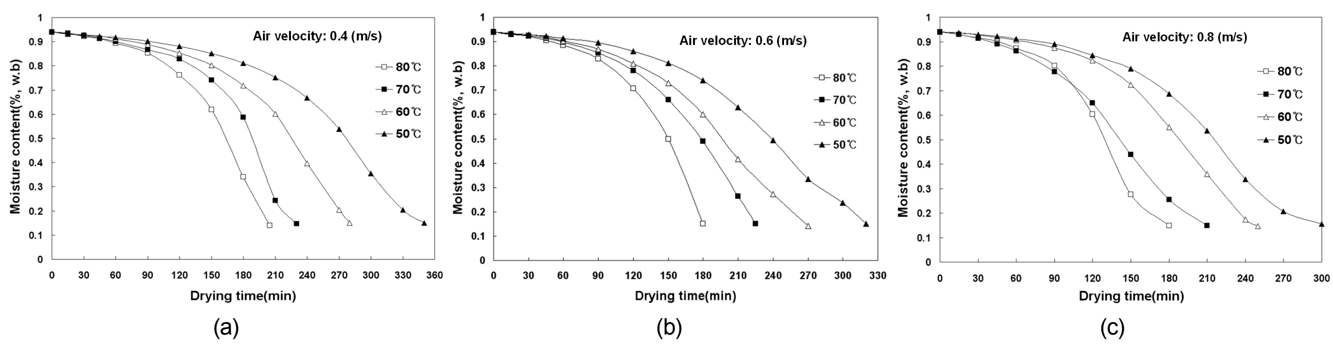

Figure 2. Influence of drying temperature and air velocity on moisture content of radish: (a) air velocity of 0.4 m/s; (b) air velocity of 0.6 m/s; (c) air velocity of 0.8 m/s.

air velocity of 0.8 m/s, the drying time was 300, 250, 210, and 180 min at the same temperatures levels. The results indicated that a high far infrared drying temperature and air velocity shortened the drying time. This was because the diffusion of moisture inside the radish was fast. The heat transfer of the far infrared rays increased at a high temperature and air velocity, and the diffused moisture evaporated quickly.

Color

Figure 3 shows the color changes (ΔE) under different drying conditions. A high drying temperature and a low air velocity increased the ΔE values.

At a temperature of 50°C, the ΔE values with air velocities of 0.4, 0.6, and 0.8 m/s were 4.94, 4.00, and 2.58, respectively, and at a temperature of 60°C, the ΔE values with these same respective air velocities were 5.70, 5.60, and 5.05, respectively. In addition, at a temperature of 70°C, the ΔE values with these same respective air velocities were 5.78, 4.76, and 4.39, respectively, and the ΔE values with a velocity of 0.4, was higher than those of other two velocity levels (0.6 and 0.8 m/s) by 1.02 and 1.39, respectively. At a temperature of 80°C, the ΔE values with air velocities of 0.4, 0.6, and 0.8 m/s were 6.94, 6.74, and 5.34, respectively.

The ΔE values increased with a high temperature and a low air velocity because of the prolonged exposure to heat as the drying time increased.

Rehydration ratio

Figure 4 shows the rehydration ratio of the radish based on different drying temperatures and air velocities. The rehydration ratio of the dried radish increased with the increase in temperature and the decrease in air velocity, as shown in Figure 4.

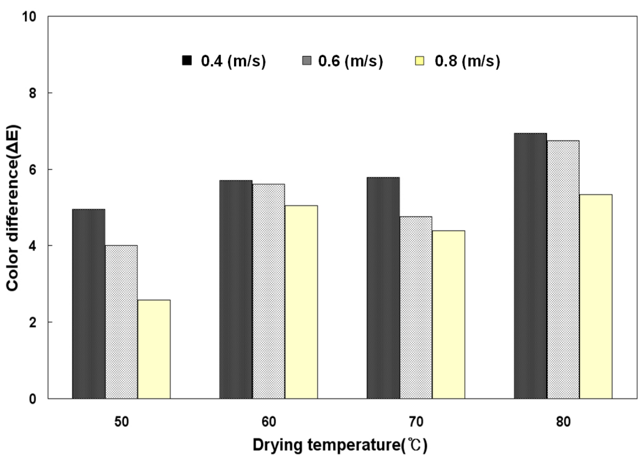

Figure 3. Comparison of color difference under different drying conditions.

The rehydration ratios at a temperature of 50°C with the three air velocities (04, 06, and 0.8 m/s) were 3.90, 3.78, and 3.60 g-water/g-dry matter, respectively, and at a temperature of 60°C they were 3.88, 4.02, and 4.22 g-water/g-dry matter, respectively. Meanwhile, the rehydration ratios at a temperature of 70°C with the three air velocities were 4.02, 3.96, and 4.19 g-water/g-dry matter, respectively, and at a temperature of 80°C they were 4.04, 4.19, and 4.58 g-water/g-dry matter, respectively. The rehydration ratio at 80°C was higher than those for the other three temperatures (50, 60, and 70°C).

Therefore, the rehydration ratio increased with the increase temperature. This result differed from that of Hwang and Rhim (1994), who found that dried vegetables at a low temperature showed high restoration rates. However,

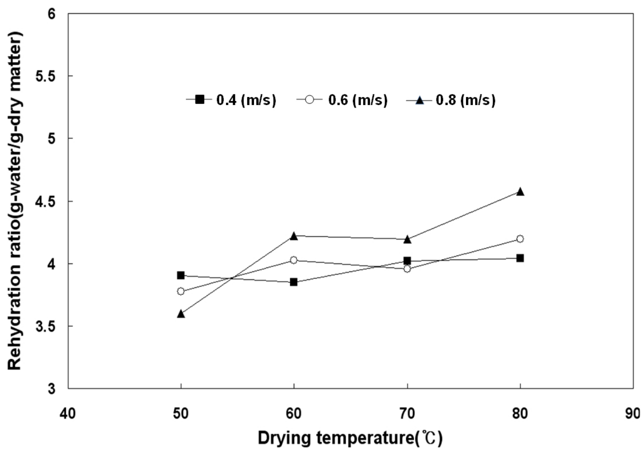

Figure 4. Influence of drying temperature and air velocity on rehydration ratio.

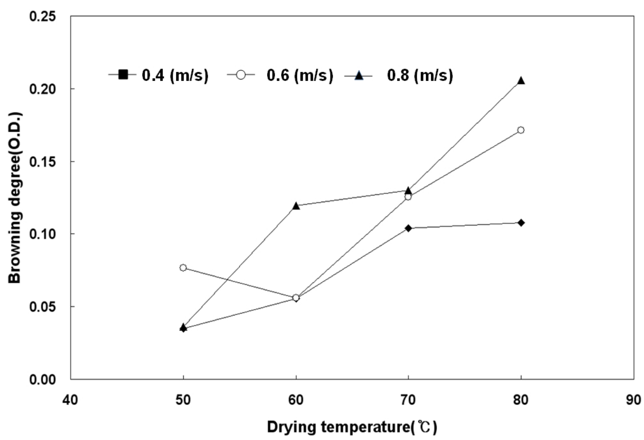

Figure 5. Influence of drying temperature and air velocity on browning.

this was because the radishes were not damaged by heat due to the decreased drying time.

Browning degree

Figure 5 shows the browning of the radishes at different drying temperatures and air velocities. The browning increased with the increase temperature and velocity.

The browning of the radish at 50°C with the three air velocities (0.4, 0.6, and 0.8 m/s) was 0.035, 0.096, and 0.036, respectively, and at 60°C the browning was 0.056, 0.056, and 0.119, respectively. In addition, at 70°C, the values were 0.104, 0.125, and 0.130, respectively, and at 80°C were 0.108, 0.171, and 0.206, respectively. Drying at 80°C showed a higher degree of browning than the those of other temperatures at 50, 60, and 70°C.

The reason for the increased browning with the increased temperature and velocity was that the browning reaction intensified with the increased temperature.

Energy consumption

Figure 6 shows the energy consumption under various drying conditions. The energy consumption at the three air velocities (0.4, 0.6, and 0.8 m/s) at 50°C was 5083.2, 4587.6, and 4360.8 kJ/kg-water, respectively, and at 60°C was 4620.2, 4416.6, and 3976.8 kJ/kg-water, respectively. In addition, the energy consumption at 70°C, was 3618.4, 3508.8, and 3027.6 kJ/kg-water, respectively, and at 80°C was 3196.8, 3015.6, and 2841.6 kJ/kg-water, respectively.

The energy consumption decreased with the increased temperature and velocity. This result was similar to the established theories that a high temperature is advantageous in terms of energy efficiency (Li et al., 2009; Ning and Han, 2012).

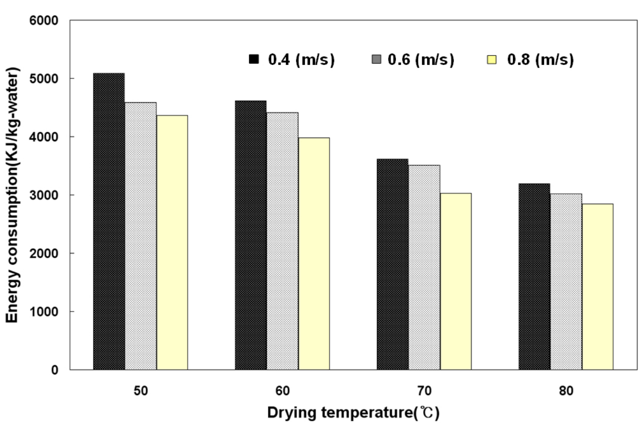

Figure 6. Comparison of energy consumption under different drying conditions.

Conclusions

This study examined the drying and quality characteristics of sliced radishes at various air temperatures and velocities under a far infrared conveyor dryer. This study also established the drying conditions of radishes by employing drying factors of four temperatures (50, 60, 70, and 80°C) and three air velocities (0.4, 0.6, and 0.8 m/s), and the sample was dried until the moisture content reached 15±0.5% (w.b.). The drying rate increased with the increase in the temperature and air velocity but decreased with time. However, the drying rate was influenced by temperature rather than velocity. When the drying temperature and air velocity were 50°C and 0.4 m/s, respectively, the drying time was the longest (350 min). However, when those values were 80°C and 0.8 m/s, respectively, the drying time was the shortest (180 min). ΔE (the color difference value) increased with the increased temperature and air velocity. The browning and rehydration ratio increased depending on the temperature rise. Energy consumption decreased with the increase in the temperature and air velocity. Based on the results of this study, the best drying conditions for radishes were determined to be a temperature of 70°C and an air velocity of 0.8 m/s.

Conflict of Interest

The authors have no conflicting financial or other interest.

Acknowledgments

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