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Research Article

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원적외선과 열풍 건조조건에 따른 오징어의 건조특성

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Drying Characteristics of Squids According to Far Infrared and Heated Air Drying Conditions

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Abstract

Drying characteristics of squids under two dry conditions were investigated using far infrared and heated air. Dry temperatures of 40, 50 and 60℃ with air speed of 0.6, 0.8 and 1.2 m/s were used for evaluating far infrared squid drying. Heated air squid drying at 40 and 50℃ with air speed of 0.8 m/s was used as a control treatment. The two drying were evaluated in terms of drying rate, color, TBA value, aerobic bacteria, cutting shear, penetration strength, and energy consumption. The drying rate of far infrared drying was relatively faster than that of heated air drying. The drying time of far infrared drying was reduced as the drying temperature increased. The color difference of far infrared dried squids was from 18.81 to 22.85, and heated air dried squid had the color different from 23.94 to 24.09. Far infrared dried squid had relatively smaller TBA values that indicate a level of rancidity. The aerobic bacteria of heated air dried squid increased from 970 $\times 10^3$ to 40,000 $\times 10^3$ CFU/g before and after drying, respectively. Far infrared dried squid had relatively smaller increase (from 970 $\times 10^3$ to 40,000 $\times 10^3$ CFU/g). The cutting shear and penetration strength for far infrared dried squids was relatively lower. In addition, far infrared squid drying consumed relatively less energy compared to heated air drying.

Keywords : Squid drying, Far infrared drying, Drying characteristics, Energy consumption

1. INTRODUCTION

Squids, which belong to sub-order Decapodiformes of the class Cephalopoda, have been traditionally enjoyed as dried seafood due to their unique texture, flavor, and high palatability (Youn, 1976). In particular, squids are known to lower cholesterol in blood, to help in normalizing blood pressure, to prevent heart diseases, and to accelerate insulin separation because they contain special nutrients like taurine, betaine, EPA (eicosapentaenoicacid), DHA (docosahexaenoic acid), and unsaturated fatty acids. Moreover, it has been reported that the squid ink has anti-cancer ingredients (Stansby, 1976; Okutani, 1976). Dried squid is popular food due to its convenient consumption and its long shelf life.

Typical methods for drying squids are sun and heated air drying. Sun drying is the most natural method because it uses sunlight and wind, but it depends on the weather and has high potential of decaying squids due to long drying time. Beside, its quality also degrades due to browning and hardening during sun drying. Squids easily turn bad in hot and humid summer because their water-soluble proteins are eluted and bacteria proliferate in them. Furthermore, their nutrients are destroyed by photochemical actions which aggravate their browning and hardening (Tsai et al., 1991).

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In heated air drying, squids pass through the hot air from a dryer. Its advantage is relatively shorter drying time. When a squid is exposed to hot air for a long time, the hardening and shrinking of its surface gets worse due to fast water loss, which changes the squid's quality such as color, texture, and nutritional value (Kim, 1990).

Far infrared radiation is an electromagnetic wave that range from 50 to 1,000 μm wavelength. The radiation energy reaches deep inside human bodies or objects and stimulates them through resonance at their unique wavelength. Far infrared radiation drying for agricultural products accelerated drying rates, improved the quality of dried products, and reduced energy consumption than heated air drying (Han, et al. 2004).

The specification for maximum moisture contents of dried squids used to be 20%. However, the moisture contents specification for dried seafood were eliminated from the Korean Food Standards Codex in 2007 to broaden dried seafood products. Thus, more effective measures are needed to prevent quality degradation such changes as oxidation, browning, and bacteria proliferation that are caused by changing moisture contents, fats, pigments, and proteins during drying. Therefore, this study aims to establish economical squid drying conditions such as, high drying rate, efficiency and quality, by comparing drying characteristics between far- infrared drying and heated air drying.

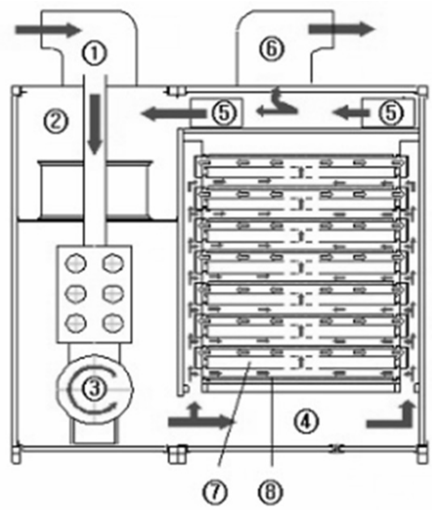
2. MATERIALS AND METHODS

A. Squid

Pre-cleaned frozen squids were used in this study. Their bodies were approximately 150 mm wide and 200 mm long. The weight of each squid was 250(±10) g, and the body thickness was 15~20 mm. The initial moisture contents were from 433 to 480 % on dry basis (d.b.), and from 81.2 to 82.8 % on wet basis (w.b.). The chromaticity of squids ranged from 55.7 to 64.4[-].

B. Far infrared and heated air drying of squids

The schematic of the far infrared dryer is in Fig. 1. The dryer dimension was 1550 (Length (L)) × 987(Width (W)) × 1956 (Height (H)) mm. It has eight sheets of 700 W far infrared heaters, and an inverter to control the air speed of the dryer for air circulation. Far infrared drying were tested



1) Air inlet, 2) Air duct, 3) Fan, 4) Plenum chamber, 5) Air duct, 6) Air outlet, 7) Sample tray, 8) Far infrared heater

Fig. 1 Schematic of a far infrared dryer.

at drying temperatures of 40℃, 50℃ and 60℃ with the air speeds of 0.6 m/s, 0.8 m/s and 1.2 m/s, respectively. Heated air drying was tested at the drying temperatures of 40℃ and 50℃ with air speed of 0.8 m/s for both temperatures. For each drying condition, 42 squids were dried, and drying was continued until the moisture contents of squids reached approximately 25 % (w.b.).

C. Measured items

1) Moisture contents

The moisture contents of squids were measured with the air-oven method: twenty grams of randomly selected dried squids were taken, and they were dried in an experimental dryer (WFO-600ND, Tokyo Rikakai, Japan) at 105℃ for 24 hours. The moisture contents of squids were determined from the ratio of the weight changes before and after drying.

2) Drying rate

The drying rate was represented by the moisture ratio. For the ratio of moisture contents, changes in squid weight were converted into the moisture contents, and the ratio of moisture contents was calculated using following equations (1) and (2) (Henderson and Perry, 1976; Keum et al., 2004):

$$MR = \frac{M_t - M_e}{M_o - M_e} \quad (1)$$

Where, MR : Moisture rate

M_t : Instant moisture contents (d.b.)
M_e : Equilibrium moisture contents (d.b.)
M_0 : Initial moisture contents (d.b.)

$$M_e \frac{M_o \cdot M_f - M_m}{M_o + M_f - 2M_e} \tag{2}$$

Where, M_m : Intermediate moisture contents (d.b.)
M_f : Final moisture contents (d.b.)

3) Chromaticity

The chromaticity change of the squid was measured by a colorimeter (JX777, C.T.S. Co, Tokyo, Japan). The L (brightness), a (redness), and b (yellowness) values were measured at six parts of the squid body before and after the drying. The averages of the five measurements were obtained, and the color difference (ΔE) was computed to identify the changes in L, a, and b values. The ΔE was determined with following equation (3) (Rhim et al., 1989):

$$\triangle E = \sqrt{\triangle L^2 + \triangle a^2 + \triangle b^2} \tag{3}$$

Where, $\triangle L$: the brightness difference of the squid body between before and after drying
$\triangle a$: the redness difference of the squid body between before and after drying
$\triangle b$: the yellowness difference of the squid body between before and after drying

4) Rancidity

The quantity of *malonaldehyde*, an oxidation product of fatty acid, was measured by the TBA test procedure (Tarladges et al., 1960). For this measurement, 20 g of dried squid sample was put into 50 mL of the 20% trichloroacetic acid solution of 2 M phosphoric acid that was cooled at 4℃ and then pulverized at 1,700 rpm for 1.5 minutes. The pulverized solution was moved to a flask, and mixed with 100 mL of distilled water. This mixed solution was filtered with a paper filter (Whatman No. 1, Whatman, England). The filtered solution of 5 mL was poured into a test tube, and the solution was mixed with 5 mL of 0.005 M 2-thiobarbituric acid in the test tube. The test tube was shaken for 10 seconds and the shaken solution was stored in dark room at room temperature for 15 hours. The absorbance of the colored sample was measured at 530 nm with a spectrophotometer (UV-1650PC, Shimadzu Co., Kyoto, Japan).

5) Bacteria test

For the general bacteria test, the dry film method of the Korean Food Standards Codex was used. A 10 g sample was mixed with 90 mL of sterile physiological salt solution. One mL of the homogenized solution was added to 9 mL of sterile physiological salt solution. This solution was diluted 10 times. The test and diluted solutions of 1 mL were injected into the PetrifilmTM Aerobic Count Plate (3M Microbiology, St. Paul, MN, USA), and the plates were cultured at 35±1℃ for 48 hours. The culturing process was repeated for each dilution. The number of cultured clusters was calculated, and the mean clusters were multiplied by the dilution rate to determine the number of general bacteria. The number of general bacteria was represented as colony-forming units per gram (CFU/g).

6) Squid rheological properties

Squid rheological properties, the shearing force and penetration strength, were measured by a Rheometer (CR-100D, Sun Scientific Co., Tokyo, Japan). Both measurements were made with adapters that penetrate approximately 3 mm on the sample size of 30 (H) × 30 (W) ×1.5 (D) mm at a speed of 60 mm/min. Wedge (No. 10) and cylinder (No. 4) adapters were used to measure shearing force and penetration strength, respectively.

7) Energy consumption

The power consumption of the far infrared dryer was measured with an electronic watt-hour meter (PEW-15-120E, PSTEC Co. Ltd, Seoul, Korea). Consumed electric energy of the far infrared dryer was converted to required energy for removing 1 kg of moisture from squids. Kerosene consumption of the heated air dryer was measured, and the energy consumption was computed with the energy density of kerosene (42.8 MJ/kg). Energy consumption of the heated air dryer was also translated into the identical energy unit.

3. RESULTS AND DISCUSSION

A. Drying rate

Figure 2 shows the change of the moisture ratios of squids according to far infrared and heated air drying conditions.

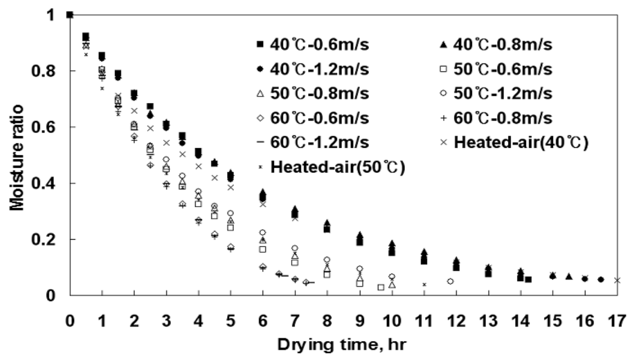


Fig. 2 Moisture ratio for the drying conditions according to the drying time.

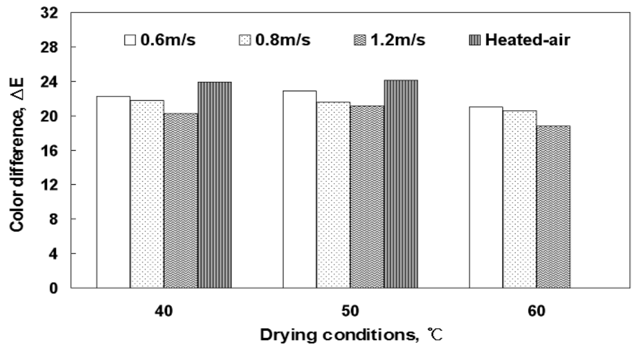


Fig. 3 Color difference according to the drying conditions.

Squid drying time was 15.5 hours and 17 hours for far infrared and heated air drying at the drying temperature of 40℃ and air speed of 0.8 m/s, respectively. By increasing the drying temperature by 10℃, the drying time was relatively shorter: total time for far infrared and heated air drying was 10 hours and 11 hours, respectively. The far infrared dryer had minimum drying time (7.3 hours) at drying temperature of 60℃ with air speed of 0.6 m/s and 0.8 m/s. The maximum drying time (16.5 hours) was observed at the drying temperature of 40℃ and air speed of 1.2 m/s.

Our results suggested that air speed negatively influenced drying time. For example, increasing air speed increased drying time at the temperature of 40℃: air speed of 0.8 m/s and 1.2 m/s increased the drying time by 1.25 and 2.25 hours, respectively, compared to air speed of 0.6 m/s. At the drying temperature of 50℃, the total drying time of the far-infrared dryer were 9.7, 10 and 10.8 hours for the air speeds of 0.6 m/s, 0.8 m/s, and 1.2 m/s, respectively. The drying at air speed of 0.8 and 1.2 m/s and the drying temperature of 50℃ required additional 0.3 and 1 hour for drying squids to desired moisture contents compared to that at air speed of 0.6 m/s. At the drying temperature of 60℃, squid drying time for the far infrared dryer was 7.3, 7.3 and 7.5 hours with air speed of 0.6, 0.8, and 1.2 m/s, respectively. The potential reason in reducing drying time at air speed of 0.6 m/s was less far infrared radiant energy loss due to air circulation.

B. Chromaticity

Figure 3 shows the ΔE values of squids before and after drying. The ΔE values of far infrared dried squids were from 20.30 to 22.24 for drying temperature of 40℃. Relatively higher range (21.20 to 22.85) of the ΔE values was observed at drying temperature of 50℃. However, a lower range of the ΔE values was observed at drying temperature of 60℃: ΔE values ranged from 18.80 to 21.02. The ΔE values of heated air dried squids were generally higher compared to far infrared dried squids: the ΔE values were 2.20 and 2.53 higher at drying temperatures of 40 and 50℃. Thus, color change in squid body was greater for heated air dried squids.

C. Rancidity

Figure 4 shows the TBA (Thiobarbituric acid) values of dried squids. Far infrared dried squids had slightly lower TBA value than heated air dried squids (0.097 (far infrared dried squid) versus 0.113 (heated air dried squid)) at drying temperature of 40℃. Similar trend in TBA values of dried squids was found out at the drying temperature of 50℃ (0.094 versus 0.098). Air speed positively influenced TBA values of dried squids. A potential reason in increasing TBA values at higher air speed was oxygen supplement increase to squids, and increased oxygen supplement to

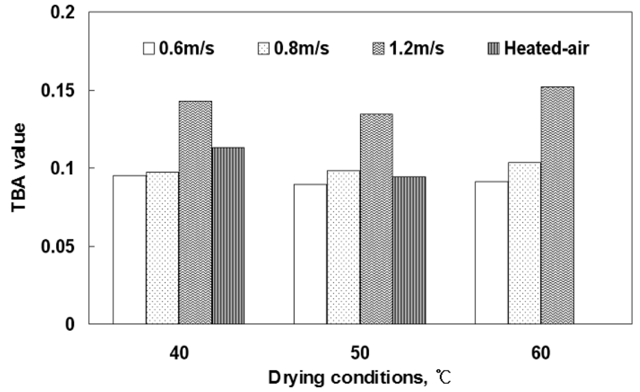


Fig. 4 TBA value according to the drying conditions.

squids expedited the oxidation process of squids. Similar results were reported by Cho (1991) and Hong et al. (2006). For example, Cho (1991) reported that increasing air volume of drying process expedited the oxidation process of drying mater due to increase of oxygen supplement. In addition, Hong et al. (2006) reported that drying temperature, oxygen, and drying rate were related with malonaldehyde, an element of the TBA value measurement.

D. Bacteria test

Figure 5 shows the aerobic bacteria of dried squids. The number of aerobic bacteria in the squids increased after drying the squids. For example, the bacteria increased from 1.1×10^3 to $1,770\times10^3$ CFU/g at after drying at the temperature of 40℃ and air speed of 0.8 m/s. Heated air drying had similar trend: the bacteria increased from 970×10^3 to $40,000\times10^3$ CFU/g after the drying. Our results generally showed that the bacteria of dried squids increased for both drying conditions, but, the heated air had relatively higher increase in the bacteria after. Drying squids increased the aerobic bacteria: the range of drying temperatures used was within proliferating conditions of the bacteria. It was found out that increasing drying temperature decreased the bacteria growth on dried squids. In addition, far infrared drying had relatively less increase of the bacteria after drying compared to heated air drying.

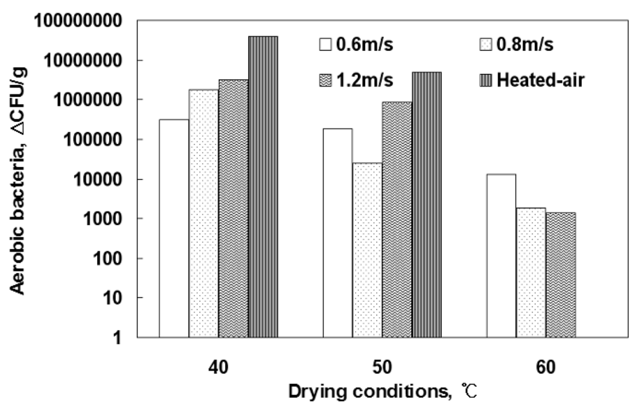


Fig. 5 Aerobic bacteria according to the drying conditions.

E. Squid rheological properties

1) Cutting shear strength

Figure 6 shows the cutting shear strength of dried squid. The cutting shear strength of heated air dried squids was relatively higher than of far-infrared dried squids. Cutting shear strength of dried squid decreased as drying temperature and air speed reduced. Cutting shear strength of 22.65 kg/cm^2 and 26.49 kg/cm^2 was observed at the drying temperature of 40℃ and air speed of 0.8 m/s for the far infrared and heated air drying conditions, respectively. Generally, squids dried from far infrared drying had relatively lower cutting shear strength compared to heated air dried squids. Therefore, far infrared dried squids may have relatively softer texture. In addition, our results indicated that increasing air speed reduced the cutting shear strength.

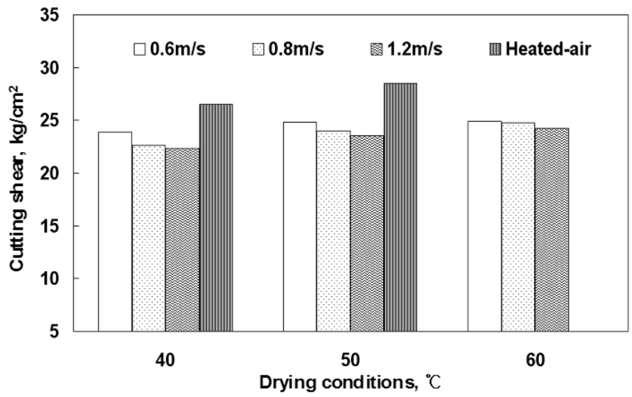


Fig. 6 Cutting shear strength according to the drying conditions.

2) Penetration strength

Figure 7 shows the penetration strength of squids at the far infrared and heated air drying conditions. The penetration strength of far-infrared dried squids was relatively lower compared to that of heated air dried squids. For example, the penetration strength of far infrared and heated air dried squids was 27.49 and 34.75 kg/cm^2, respectively, at the drying temperature of 40℃ and air speed of 0.8 m/s. Higher pene-

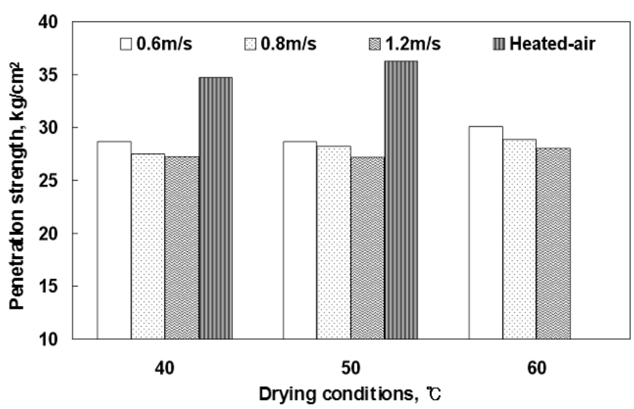


Fig. 7 Penetration strength of squids according to drying conditions.

tration strength of heated air dried squids may be due to its longer drying time because longer drying time allowed to contract and harden squid cells. The penetration strength of far-infrared dried squid increased as drying temperature increased. In addition, the air speed showed negative effects in the penetration strength.

F. Energy consumption

Energy consumption for drying squids with heated air was relatively higher compared to that of the far infrared drying at the drying temperature of 40 and 50℃ (Fig. 8). For the far infrared drying, energy consumption increased as drying temperature decreased. Moreover, energy consumption for far infrared drying generally increased with air speed increase: energy consumption increased by 0.26 kWh/kgH_2O, 0.65 kWh /kgH_2O and 1.28 kWh/kgH_2O for the drying temperature of 40, 50 and 60℃ while air speed increased from 0.6 to 1.2 m/s. Generally, energy required for far infrared drying was relatively less. For example, energy required to dry 1 kg of squid body water was 5.82 kWh/kgH_2O and 9.30 kWh/ kgH_2O for the far infrared and heated air drying at drying temperature of 40℃ with air speed of 0.8 m/s: the far infrared drying consumed 37.4% less energy. Also, higher drying temperature of far infrared drying reduced energy consumption because overall drying time was reduced due to drying rate improvement.

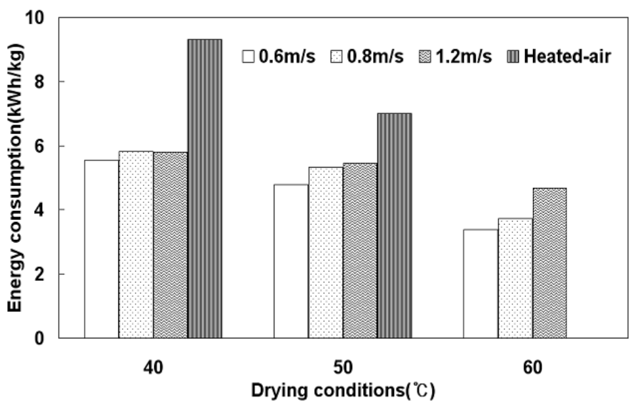


Fig. 8 Energy consumption by the drying conditions.

4. CONCLUSIONS

The study investigated characteristics of far infrared and heated air drying dried squids to establish the optimum drying conditions for preserving squid quality. In addition, the performance of two drying methods was examined in terms of drying time and energy consumption to improve the drying efficiency. The results of our study showed that far infrared drying method showed better performed in drying squids in terms of drying time, and energy consumption. Conclusions of the study are as follows:

(1) The drying rate of far infrared drying was relatively faster than that of heated air drying. The drying time of far infrared drying was reduced as the drying temperature increased.
(2) Changes in squid chromaticity decreased as the temperature and air speed of far infrared drying increased. The chromaticity change in far infrared dried squids was less than the change in heated air dried squids.
(3) The TBA value increased after drying squids. Increasing air speed was beneficial to minimize the TBA value increase.
(4) The number of general aerobic bacteria increased after drying squids under both drying conditions. However, far infrared drying had relatively less bacteria increase. Increasing drying temperature reduced the aerobic bacteria proliferation.
(5) The cutting shear and penetration strength of heated air dried squids were relatively higher. Relatively lower cutting shear strength of far infrared dried squids was achieved at low drying temperature (40℃) and high air velocities (1.2 m/s).
(6) Far infrared drying required relatively less energy at high temperature (60℃). At the high temperature, the lowest air speed (0.6 m/s) consumed the least energy to dry squids. The energy consumption in heated air drying was generally higher compared to that of far infrared drying.

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