A Mathematical Model for Color Changes in Red Pepper during Far Infrared Drying

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Abstract

Purpose: The color changes in red pepper during far infrared drying were studied in order to establish a color change model.
Methods: The far infrared drying experiments of red pepper were conducted at two temperature levels of 60, 70 ℃ and two air velocity levels of 0.6 and 0.8 m/s. The results were compared with the hot-air drying method. The surface color changes parameters of red pepper were measured qualitatively based on L (lightness), a (redness), b (yellowness) and total color changes (ΔE). The goodness of fit of model was estimated using the coefficient of determination (R²), the root mean square error (RMSE), the mean relative percent error (P) and the reduced chi-square (χ²).
Results: The results show that an increase in drying temperature and air velocity resulted in a decrease in drying time, the values of L (lightness) and a (redness) decreased with drying time during far infrared drying. The developed model showed higher R² values and lower RMSE, P and χ² values.
Conclusions: The model in this study could be beneficial to describe the color changes of red pepper by far infrared drying.

Keywords: Color changes, Far infrared drying, Mathematical modeling, Red pepper

Introduction

Pepper (Capsicum annuum L.) is native to Mexico, and has been utilized popularly worldwide. Pepper is a good source of vitamin A and C (Lee et al., 1995), especially vitamin C content ranks the first among the all green vegetables. Red pepper made by drying and is used to cook various food stuffs. It can either be used in industry or medical applications (Isidoro et al., 1995).

The annual consumption of red pepper is 20 million ton and covers 30% of the total vegetable production in Korea (Jeong et al., 2011). It played a prominent role in Korean foods. Typical drying methods for red pepper are sun drying and hot air drying. Sun drying is the most natural method as it uses sunlight and wind, but it depends on the weather condition. The drying of red pepper under sun light is risky, because it takes a long time and red pepper is easy to deteriorate and infected with dust insect mold and bacteria. The hot air drying needs a lot of resources for the drying equipment and it entails energy cost (Bae et al., 2003). But the far infrared drying has some advantages over convective hot air drying. Heat transfer coefficients are high, the drying rate is fast and the energy cost is low (Kang et al., 2011). Moreover, drying of agricultural products by far infrared radiation accelerated drying rates and enhanced quality of the dried products (Sakai et al., 1994).

Extensive research efforts have been paid to investigate the drying characteristics or drying models of the red pepper by sun, vinyl house and hot air drying (Yoon and Lee, 2004), microwave-convective drying (Soysal et al., 2009), hot air drying, electrical heater and lamp drying (Kooli et al., 2006)...
A survey of consumer opinions showed that the major factor for deciding the quality of red pepper was color (redness). The red color in pepper represents various carotenoid pigments such as cryptocapsin, capsorubin and capsanthin, which cover 34.7% of the total pigmentation (Hornero and Minguez, 2001). Therefore the measurement of color is the most important factor to evaluate the drying behaviour of red pepper. However, the studies on the color changes of red pepper are scarce. Therefore, in this work we investigated the effect of far infrared drying temperature and air velocity on drying rate and color changes of red pepper, and to establish the color changes model in order to predict the changes of redness and lightness with time by far infrared drying. Finally we used the coefficient of determination ($R^2$), the root mean square error (RMSE), the mean relative percent error (P) and the reduced chi-square ($\chi^2$) to evaluate the goodness of fit of established model.

**Materials and Methods**

**Materials**

The red peppers used in this study were obtained from Chongwon-Gun of Korea, during the summer season. Red peppers were stored in storage at 5°C until conducting the experiments. The length, diameter and weight of red peppers were 13~15 cm, 2.0~2.4 cm and 13~15 g, respectively. The initial moisture content was 80.5~82.6% on a wet base (wb) and the initial color values were 28.45~32.33 (L-lightness), 36.06~41.97 (a-redness) and 26.53~28.55 (b-yellowness).

**Experimental apparatus**

The schematic diagram of the experimental apparatus is shown in Figure 1. The dimension of the dryer that used in this experiment was 5500×1800×900 mm (L×H×W). The dryer was composed of far infrared heater (MEP-550, Restoration, Korea), drying chamber (L×H×W, 5340×620×90), belt conveyer, blast fan (DTB-402, Dongkun, Korea), control panel which can control the temperature of far infrared heater, belt speed and air velocity. Another dryer (Model BOPP-1.5, Shinheung Co., Korea) was also used for hot air drying experiment.

**Experimental methods**

Based on the result of our preliminary experiment, the far infrared drying test was conducted at the drying temperatures of 60°C and 70°C with air velocities of 0.6 and 0.8 m/s. For comparative analysis, the hot air drying temperatures were maintained at 70°C (dry-bulb temperature) and 60°C (wet-bulb temperature) for 6 h, and 55°C (dry-bulb temperature) and 35°C (wet-bulb temperature) for 18 h. Approximately 10 kg sample of red pepper was used for each drying condition, and dried until the final moisture content reached at 17±0.5% (wb).

**Analysis**

**Drying rate**

The initial moisture content was measured with the air-oven method. Twenty grams of randomly selected samples were taken and dried in an experimental dryer (WFO-600ND, Tokyo Ri-kakai, Japan) at the temperature of 105°C for 24 h, and the moisture content was determined from the ratio of the weight changes before and after drying.

The drying rate was represented by the moisture ratio (MR). For determination of moisture ratio, the moisture content was measured at each time and converted into the moisture ratio by using Equation (1) and (2) (Henderson and Perry, 1976; Li et al., 2009).

\[
MR = \frac{M_t-M_e}{M_0-M_e} \quad (1)
\]

\[
M_e = \frac{M_0M_t-M_m}{M_0+M_t-2M_e} \quad (2)
\]

where MR is moisture ratio, $M_0$, $M_t$, $M_m$, $M_e$ are equilibrium, initial, middle and final moisture content, respectively. Since the $M_e$ is relatively smaller than that of $M_t$ or $M_0$, for calculate accurately, the moisture ratio (MR) was calculated by $(M_t-M_e)/(M_0-M_e)$.

**Figure 1.** Schematic diagram of a far infrared dryer: (1) Blast fan, (2) Far infrared heater, (3) Motor, (4) Drying chamber, (5) Belt conveyer, (6) Blast pipe.