Mathematical models and qualities of shredded Thai-style instant rice under a combined gas-fired infrared and air convection drying

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Abstract. Instant food is a product produced for convenience for consumer. Qualities are an important attribute of food materials reflecting consumer acceptance. The most problem of instant rice is casehardening during drying process resulted in the longer rehydration time. The objective of this research was to study the qualities of shredded Thai-style instant rice under a combined gas-fired infrared and air convection drying. Additionally, the mathematical models for gas-fired infrared assisted thin-layer drying of shredded Thai-style rice for traditional was investigated. The thin-layer drying of shredded Thai-style rice was carried out under gas-fired infrared intensities of $1000W/m^2$, air temperatures of 70^oC and air velocities of 1 m/s. The drying occurred in the falling rate of drying period. The Page model was found to satisfactorily describe the drying behavior of shredded Thai-style rice, providing the highest R^2 (0.997) and the lowest MBE and RMSE (0.01 and 0.18) respectively. A 9 point hedonic test showed in softness and color, but odor and overall acceptance were very similar.

1. Introduction

In today's modern world, competitive social pressures cause people in large cities to turn to meals that save time and can be eaten quickly. Many of the most favorite meal types are the ready to eat instant meals and instant rice. The advantages of infrared technology in dehydrating foods were included decreased drying time, high energy efficiency, high quality finished products, uniform temperature in the product and a reduced necessity for air flow across the product [1]. The mathematical models are needed in the design and operation of a dryer[2]. Several researchers have developed mathematical models for natural and forced convection drying systems. However, the mathematical model for infrared assisted thin-layer drying of shredded Thai-style rice at low relative humidity could not be found in the literature. Therefore, the purpose of this present study was to develop the combined gas-fired infrared drying and tray-desiccant unit dryer.

2. Experimental

2.1 Material preparation and drying

A schematic diagram of a combined gas-fired infrared burner and air convection drying used for experiments is shown in **Figure 1.** The drying process was conducted at temperature of $70^{\circ}C$, air velocity of 1 m/s and gas-fired infrared burner intensities at $1000W/m^2$.
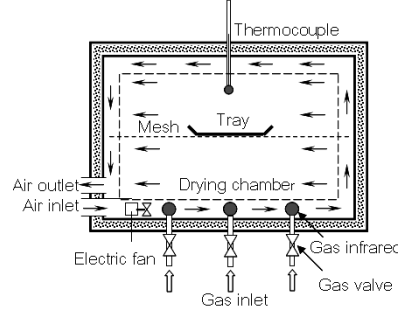
Figure 1. Schematic diagram of combined gas-fired infrared burner and air convection dryer

2.2 Drying experiments

In each drying condition, 1,000 g of the freshly shredded Thai-style rice was uniformly spread on a mesh tray placed in the drying chamber. The moisture contents of the samples were determined according to AACC method [3]. The samples with final moisture content of approximately 6% (d.b.) were kept in polypropylene bags the cold storage at $4^{\circ}C$ for further quality evaluation. Drying curves were fitted with five thin-layer drying models, namely, the Lewis, the Page, the Modified Page, the Henderson and Pabis and the Logarithmic models (Table 1).

Table 1. Thin-layer drying model given by various authors for drying curves

Model name	Model	Referents
Lewis	MR = exp(-kt)	[4]
Page	$MR = exp(-kt^n)$	[4]
Modified Page	$MR = exp(-kt)^n$	[5]
Henderson and Pabis	MR = a exp(-kt)	[5]
Logarithmic	MR = a exp(-kt) + c	[5]

The moisture ratio (MR) of shredded Thai-style rice during drying experiments was calculated using the following equations:

$$MR = \frac{(M_t - M_e)}{(M_0 - M_t)} \qquad (1)$$

where M is the moisture content of the product at each moment, M_e is the equilibrium moisture content and M0 is initial moisture content of the product. The values of M_e are relatively small compared with M or M_0 for long time. The goodness of fit of the tested mathematical models to the experimental data was evaluated with the correlation coefficient (R^2), mean bias error (MBE) and root mean square error (RMSE). The higher of the R^2 values and the lower of the MBE and RMSE value, the better is the goodness of fit. Correlation coefficients and error analyses, thus simplifying Eq.(2-5)

$$R^2 = 1 - \frac{\sum_{i=1}^{N}\left(X_{pre,i} - X_{exp,i}\right)^2}{\sum_{i=1}^{N}\left(X_{pre,ave} - X_{pre,i}\right)^2} \qquad (2)$$

$$EF = \frac{\sum_{i=1}^{N}\left(X_{expd,i} - X_{exp,ave}\right)^2 - \sum_{i=1}^{N}\left(X_{pre,i} - X_{exp,i}\right)^2}{\sum_{i=1}^{N}\left(X_{exp,i} - X_{exp,ave}\right)^2} \qquad (3)$$

$$\text{RMSE} = \sqrt{\frac{1}{N}\sum_{i=1}^{N}\left(X_{pre,i} - X_{exp,i}\right)^2} \tag{4}$$

$$\chi^2 = \frac{\sum_{i=1}^{N}\left(X_{pre,i} - X_{exp,i}\right)^2}{N-z} \tag{5}$$

where $X_{exp,i}$ is the ith experimental values, $X_{pre,i}$ is the ith predicted values, N is the number of observations and z is the number of constants.

2.3 Color determination
Colors of the shredded Thai-style rice determined on *L, a* and *b* . Hunter Lab colorimeter (MiniScan XE Plus, Hunter Associates Laboratory, Inc., USA) were measured of the samples before and after drying. The color indices represent light to dark ($0 \leq L \leq 100$), green to red ($-60 \leq a \leq 60$), and blue to yellow ($-60 \leq b \leq 60$). Ten replicates of the color test were performed and the average values of color changes were reported.

2.4 Rehydration analysis
The shredded Thai-style rice were carried out by adding 10 g of the samples in 100 mL of boiling water ($\approx 80^0 C$), boiling for 5 min and then draining the excess water. Rehydration ratio defined as a ratio between mass of the sample after and before rehydration was determined. Ten replicates of the rehydration test were performed and the average values of rehydration ratios were reported. It is defined as a ratio between mass of the sample after (m_{after}) and before rehydration (m_{before}).

$$\text{Rehydration ratio} = (m_{after})/(m_{before}) \tag{6}$$

2.5 Sensory evaluation
A 9 point hedonic test was evaluated by 30 panelists, who had been screened for perception as a basic taster. The voluntary consumers rinsed their mouths with water, tasted samples and recorded degree of satisfaction. The 9 point hedonic scale[6] (1 = dislike extremely, 2 = dislike very much, 3 = dislike moderately, 4 = dislike slightly, 5 = neither like or dislike, 6 = like slightly, 7 = like moderately, 8 = like very much, 9 = like extremely) was used as a device for the sensory evaluation.

3. Results and Discussions

The curves indicated that moisture ratio decreased rapidly at the first stage of drying and gradually decreased to the equilibrium values. The gas-fired infrared burner intensities $1000 W/m^2$ was found to help enhance moisture removal from the product. This was probably because the higher gas-fired infrared burner intensity induced a rapid increase of the temperature at the surface of product, resulting in an increase of the water vapor pressure inside the product and thus in higher drying rate[6]. The Page model showed a good fit curves than the other models, namely, the average values of R^2, MBE and RMSE were 0.9972, 0.00 and 0.178, respectively. Colors of the shredded Thai-style rice compare between the freshly shredded Thai-style rice and after the drying are shown in **Figure 3-4**. It can be seen that lightness (*L*-values) increased from 65.12 (freshly shredded Thai-style rice) to 82.39, the color indices (*a*-values) was not pronounced, whilst yellowness (*b*-values) ranged from 11.70 to 14.12
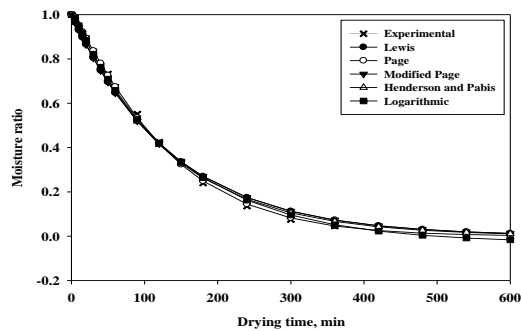
Figure2. Comparison between values of five thin layer drying models and experimental at 70°C

Figure 3. Freshly shredded Thai-style rice   **Figure 4.** The shredded Thai-style instant rice

The influence of drying temperature from 1000W/m^2 increase in rehydration ratio by 40.2% and 59.3%. As earlier described that the higher temperature induced a larger pore, such a high volume expansion of the pore enhanced water absorption during rehydration and greater water retention inside the material cells, results in the higher degree of rehydration. The 9 point hedonic scales of the shredded Thai-style instant rice showed in softness and color and overall acceptance were very similar.

4. Conclusion
The combined gas-fired infrared burner and hot air drying could improve color, degree of rehydration, of the product. The shredded Thai-style instant rice tended to be lighter when using the higher drying temperature. The drying temperature increase in rehydration ratio by 40.2% and 59.3%. Resulted in the greater rehydration capability and the sensory test on softness and color of the product.

5. Acknowledgement

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