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Cassava slices drying by using a combined hot-air single-plane microwave dryer

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ABSTRACT

Characteristics of cassava drying were investigated by using a microwave hot-air drying system. Two waveguides were installed on a single plane of the microwave cavity. The drying experiments were carried out at two levels of sample surface temperature set-points, 70˚C and 80˚C respectively. Cassava (Rayong-9) with 2.5 kg weight and 61% moisture content on wet basis was dried in the dryer for about 300 - 340 minutes until the final values of moisture content of about 20% db were achieved. It was found that the drying time decreased with an increase in sample-surface temperature set point. Approximately 87% of the moisture was removed during the drying period. It was found that there was a rapid decrease in moisture ratio values followed by the gradual decline period in all experiments. With regard to drying kinetics, 5 commonly used mathematical models were examined with the experimental data. It was found that Page's and diffusion models provided a good agreement between the experimental and predicted moisture ratio values for all temperature set-points. The regression results indicated that highest values of coefficient of determination and adjusted coefficient of determination as well as lowest value of standard error of estimation were reported for the case of Page's model at 80˚C temperature set-point.

KEYWORDS

Microwave Drying; Cassava; Drying

1. INTRODUCTION

Thermal drying may be defined as the process of thermally removing moisture to yield a solid product. Two processes simultaneously take place during thermal drying. These processes are the evaporation of surface moisture and the internal moisture transferring of the drying product. The energy from the surrounding environment, as a result of convection, conduction, radiation, or the combination of these effects, is transferred to the drying product to evaporate the surface moisture. In addition, the movement of internal moisture to the surface of the drying product may occur through several mechanisms such as diffusion, capillary effect as well as an increase in internal pressure of the material.

According to the conventional hot-air dryer and solar drying, several kinds of materials have been investigated with regard to their drying characteristics. The effect of drying time on chili-pepper moisture ratio was studied by a researcher from Nigeria [1]. Four drying models viz. Newton, Henderson and Pabis, Page, and Logarithmic models were fitted in the experimental data by using regression technique. The solar drying characteristics of 3-shapes strawberry, whole, halves quarter and 3 mm discs, were investigated by Egyptian researchers [2]. Moreover, the effect of drying temperature, 50˚C to 80˚C, on drying rates of apple slice was studied [3]. Several thin-layer drying equations were fitted to the experimental drying data in order to examine the most appropriate equation. For the case of banana drying, empirical and diffusion models were utilized to describe the characteristics of intermittent and continuous solar drying [4]. A least square method was used for drying model fitting in order to minimize the standard error between the experimental data and the calculated values.

One of the promising drying techniques is microwave method, which is considerably different from the conventional drying. The electromagnetic field in microwave drying interacts with the drying material as a whole while the hot-air drying depends on the rate of heat propagation from higher-temperature material surface to the inside. The researchers from Turkey investigated the drying characteristics of spinach using 8 microwave power levels. It was found that the drying process was completed between 290 to 4005 s depending on the value of microwave power [5]. Microwave drying in combination with hot air drying was also used for pumpkin slices

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drying [6]. Drying periods for the case of microwave, hot air, and combined microwave-air drying methods were studied. It was reported that the latter was accounted for the shortest drying period.

The aim of this study was to evaluate the drying characteristics of combined microwave-air method for the case of cassava. Furthermore, the mathematical model parameters were also calculated by using regression technique.

2. MATERIAL AND METHOD

2.1. Material

Rayong-9 cassavas with an initial moisture content of 61% on wet basis were obtained from a local factory in Phitsanulok, Thailand. Their initial moisture content value was examined, according to ASAE S358.2 DEC99 standard, by using a cabinet hot-air dryer (Memmert 600, 30˚C - 350˚C, 2400 W) and a digital balance (accuracy 0.001 g). Then, the material was cut into 10 mm thick and 25 - 50 mm diameter with the cutting machine. All cassavas used in the experiment were from the same batch.

2.2. Drying Experiment and Data Analysis

The drying system was comprised of two 86 × 43 mm rectangular waveguides, two air-cooled magnetrons, and a 44 × 51 × 93 cm cavity. Two 800 W-magnetrons used in the experiments work at the frequency of 2.45 GHz. They were installed in the waveguides mounted on the same plane, the top of the cavity. Four heaters, 2 kW each, were installed at the air inlet duct. A temperature controller (Shimax MAC5D) and type K thermocouple were utilized for temperature control purpose. In order to record the sample weight loss, a 15 kg single-point load-cell coupled to a load cell indicator (Primus CM 013) was installed on the top of the cavity. Additionally, A Testo 435, accuracy ±0.25˚C and ±2% RH, was used for measuring the temperature and relative humidity of inlet air.

In all experiments, approximately 2.5 kg of samples were used. The samples were uniformly spread on a drying tray and placed in the drying cavity. The temperature and velocity of hot air were set at 60˚C and 1 m/s respectively. A temperature sensor was utilized for measuring surface temperature of the sample. It was used as an input for microwave power operation control. The experiments were investigated at two levels of sample temperature viz. 70˚C and 80˚C respectively.

The values of moisture ratio were calculated using the following equation:

$$MR = \left(M_t - M_e\right)/\left(M_i - M_e\right) \quad (1)$$

where:

MR is the moisture ratio;

Mt is the moisture content at 1 hour (%);

Me is the equilibrium moisture content (%);

Mi is the initial moisture content (%).

Several conventional drying models have been proposed for determining the moisture ratio as a function of drying time. In this research, the drying models of cassava drying by using 2 planes magnetron microwave-air drying system were investigated. Newton model [7], Page's model [8], logarithmic model [9], Henderson & Pabis model [10], and diffusion model [3] were applied to describe the characteristics of cassava drying.

$$MR = \exp\left(-kt\right) \quad (2)$$

$$MR = \exp\left(-kt^n\right) \quad (3)$$

$$MR = \left(a\right)\exp\left(-kt\right) + b \quad (4)$$

$$MR = \left(a\right)\exp\left(-kt\right) \quad (5)$$

$$MR = \left(a\right)\exp\left(-kt\right) + \left(1-a\right)\exp\left(-ktb\right) \quad (6)$$

where:

k is the drying constant;

n is the power parameter;

a and b are parameters;

t is drying time (hour).

Coefficient of determination (R^2), adjusted coefficient of determination $\left(R^2_{adjusted}\right)$, and standard error of estimation (SEE) were utilized to evaluate the goodness of fit of the tested drying models to the experimental data.

3. RESULT AND DISCUSSION

Effective mathematical model of drying characteristic is crucial for cassava microwave-air drying kinetics investigation. The combination of microwave and hot-air energy were able to reduce the sample moisture content from 61% to 8% db in 300 - 340 minutes depending on the levels of sample temperature set point. It was found that as the set-point temperature increased, the drying time was decreased. By using non-linear regression technique, the drying constants and coefficients of the five models obtained are shown in **Table 1**.

In order to evaluate goodness of fit, coefficient of determination (R^2), adjusted coefficient of determination $\left(R^2_{adjusted}\right)$, and standard error of estimation (SEE) were also computed. The goodness of fit was determined by the higher R^2 and $R^2_{adjusted}$ values as well as the lower SEE values. For all cases, it was found that R^2 and $R^2_{adjusted}$ values were higher than 0.98, and SEE values were lower than 0.029.

Furthermore, it was found that diffusion and Page's models gave the excellent fit results for all the experimental data. For the case of diffusion model regression, the values of R^2, $R^2_{adjusted}$ and SEE for 70˚C - 80˚C set-

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Table 1. The drying constants and parameters of five drying models.

Model	The drying constants and coefficients			
	k	a	b	n
Newton				
80˚C	0.54348			
70˚C	0.45176			
Page's				
80˚C	0.56965			0.93884
70˚C	0.50033			0.89054
Logarithmic				
80˚C	0.51691	0.98288	−0.00936	
70˚C	0.43869	0.95491	0.00621	
Henderson & Pabis				
80˚C	0.52998	0.97663		
70˚C	0.43146	0.95907		
Diffusion				
80˚C	0.54348	2.86555	0.99999	
70˚C	0.39875	0.88591	7.12935	

point temperature were 0.9948 - 0.9955, 0.9941 - 0.9948, and 0.0204 - 0.0207 respectively. With regard to Page's model, the values of these three criteria were found to be 0.9935 - 0.9969, 0.9931 - 0.9966, and 0.0163 - 0.0224 respectively. Normal probability plots of residuals of these models are shown in **Figures 1-4**.

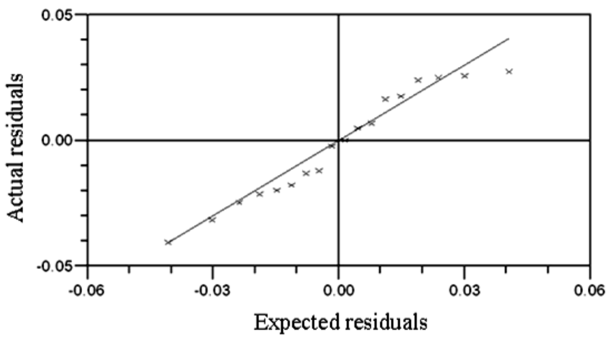

Figure 1. Normal probability plot of residual of Page's model for the case of 70˚C.

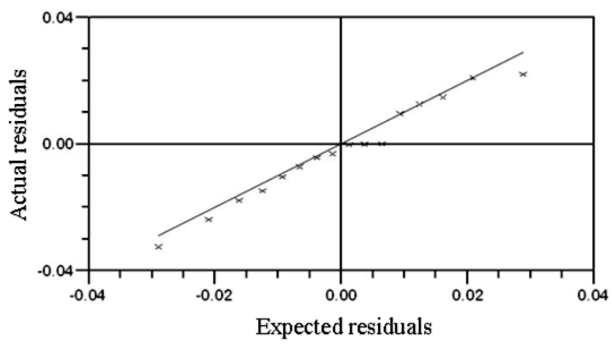

Figure 2. Normal probability plot of residual of Page's model for the case of 80˚C.

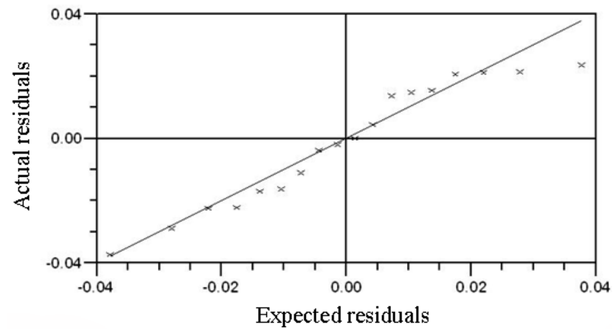

Figure 3. Normal probability plot of residual of Diffusion model for the case of 70˚C.

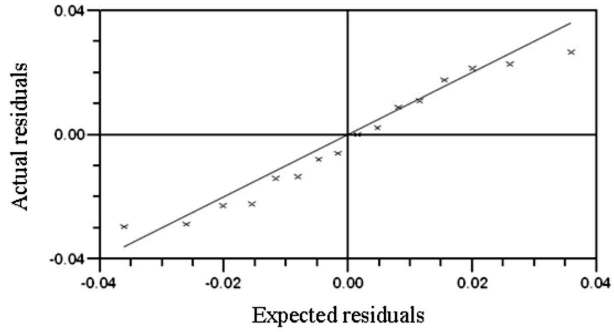

Figure 4. Normal probability plot of residual of Diffusion model for the case of 80˚C.

4. CONCLUSION

Drying kinetic of cassava in a single-planes microwave hot-air oven was investigated. Drying time decreased with an increase in sample-surface temperature set point. Approximately 87% of the moisture was removed from the sample during the 300 - 340 minutes drying-period. The rapid decrease in moisture ratio values followed by the gradual decline period was found in all experiments. With regard to 5 drying models applied to describe the drying kinetic of the sample, it was found that diffusion and Page's models provided a good agreement between the experimental and predicted moisture ratio values. High values of coefficient of determination and adjusted coefficient of determination as well as low value of standard error of estimation were also reported for the case of these two models.

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