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Evaluation of Page Model on Drying Kinetics of Red Chillies

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Abstract - The thin layer drying kinetics of chillies (Capsicum annuum L) at different layers were experimentally investigated in a natural convective solar dryer with layer thicknesses of 1cm, 2cm and 3cm. The chillies were dried from an initial moisture content of about 81. 23% (w.b) to a moisture content of 7. 13% (w.b) and the moisture content of chillies were determined at 3 hours interval. The drying data were fitted with Page model. The values of the drying constants for the model was determined. The performance of the model was investigated by comparing the correlation coefficient (r), chi-square and root mean square error (RMSE) between the observed and predicted moisture ratios. The effects of layer thickness of chillies on the drying characteristics and drying time of drying process were evaluated. The results have shown that an increase in the drying layer thickness causes longer drying times. According to the results, Page model was found to be suitable for drying chillies with 1 cm layer thickness. The model satisfactorily described the drying curve of chillies with correlation coefficient of 0.814 and 0.022 and 0.132 for chi square and RMSE respectively

I. INTRODUCTION

Drying is one of the preservation methods of agricultural products and also complex thermo-physical and biochemical process comprising simultaneous heat and mass transfer between the surface of the material and the surrounding media (Hossain and Bala, 2002). Mathematical models have proved to be very useful for analyzing these transfer processes during drying. Different types of solar dryers for drying of biological materials have been reviewed by Farkas (2004). Although for commercial production of agricultural products, forced convection solar dryer provides a better control of drying air, they require additional energy for drying operation. Hence, natural convection solar dryer is highly preferred for drying food products, especially when in thin layers (Pangavhane et al., 2002).

Modeling the drying kinetics and determining the drying time of chillies are two very important areas of drying. However, most production losses in the industry occur during drying. In order to minimize these losses, it is necessary to optimize the drying conditions, machine design, and product quality. There is a need to identify and evaluate the drying mechanisms, theories, applications, and comparison of thin-layer drying models of chillies available in the literature.

A mathematical model is an important tool used to estimate the drying time of agricultural products, instead of conducting real experiments. So far, a number of mathematical models have been developed to describe the drying process agricultural products. Further, thin layer drying models have gained wide acceptance to design new or simulate the existing system or for the analytical drying solutions. Many researchers have used the exponential drying model in describing the drying behavior of the food materials. However, little information is available on solar drying of chillies under local climatic conditions. Therefore, this research study was carried out with an objective to evaluate the drying kinetics of chillies in a natural convection solar dryer using the Page model.

II. MATERIALS AND METHODS

A. Materials

Fresh red chillies were cleaned without any unwanted materials and dirt and stored in a refrigerator maintained at 4^0C until the drying experiments. Before the experiments, the samples were taken from the refrigerator and allowed to equilibrate with room temperature (about 27± 1°C). The chillies were allowed to dry in a solar dryer between 8 a.m. to 4 p. m on bright sunny days.

B. Drying in natural convection solar dryer

A Solar dryer developed in the Department of Agricultural Engineering, Eastern University, Sri Lanka was used. Figure 1 shows the schematic diagram of natural convective solar dryer used to carry out the study. The dryer has a drying chamber, fitted with glass between the inlet and the drying chamber for the penetration of sunlight. The chimney of 15 cm diameter and 90 cm height fixed at the top of the dryer.

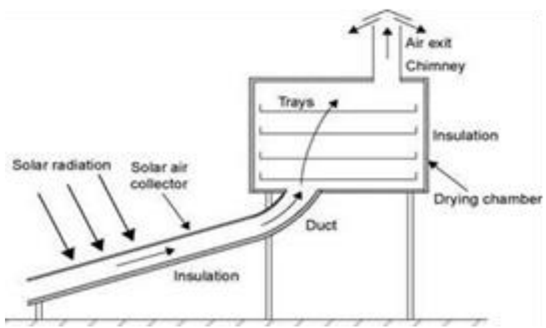

Figure 1. Cross sectional view of natural convection solar dryer

C. Experimental Treatments

The samples were removed from the refrigerator and their temperature was allowed to become equilibrium with that of atmospheric temperature, resulting in a reduction in thermal stress during drying. Drying treatments were performed in a natural convection solar dryer. The samples were dried from a high moisture level of 90.303 % (wb) to 7.13 %. Chilies with a layer thickness of 1 cm, 2 cm and 3 cm were used for the drying experiments. Each drying run lasted one hour and the reduction in weight was measured between runs. Samples were dried up to an equilibrium moisture content of 7.13%. The weights of the samples were taken using an electronic balance at 3-hour interval until the weight was constant (samples attained equilibrium moisture content with the drying air conditions). The final moisture content of the samples was determined by the standard oven drying method and the value obtained was taken as the equilibrium moisture content of the sample. Three replications of each experiment were performed, and the mean values were used for data analysis. During drying both moisture content and temperature of samples were assumed to be uniform throughout the layers at any given time.

D. Determination of moisture content

The initial moisture content, MC (% wb) of the chillie samples was determined using the standard oven dry method. Three (3) replicates, each of about 50 g weight, were weighed using an electronic balance. After pre-conditioning the oven to a temperature of 105°C, the samples were put in the oven for 24 h. The final weights were obtained and an average of the three were determined.

E. Drying rate

Drying rate (DR) was expressed by equation 2 as reported by Kaya *et al*. (2007).

$$DR = \frac{M_t - M_{t+\Delta t}}{\Delta t} \text{ .... Equation 2}$$

Where:

$M_{t+\Delta t}$ - the moisture content of the products after elapsed drying time,

Δt - change in time

M_t - moisture content at time given t

t - drying time in hours

F. Drying kinetics

The moisture ratio of chillies dried under solar cabinet dryer and by open sun drying at a given time,‘t’ was calculated using the following relationship as reported by Goyal *et al.* (2006) and Akoy (2014):

$$MR = \frac{M_t - M_e}{M_i - M_e} \text{ .... Equation 3}$$

Where,

M_i – initial dry basis moisture content (%)

M_e - equilibrium dry basis moisture contents (%)

M_t is dry basis moisture content at any time‘t’

Page Model

$$MR = \exp(-Kt^n) \text{ .... Equation 4}$$

Where;

MR = moisture ratio (dimensionless)

k = drying constant (h^{-1}) t = drying time (h)

n = drying constant

G. Determination of drying constants

The Page Model was transformed for the determination of the constants as follows:

$$MR = \exp(-Kt^{n})$$
$$lnMR = -Kt^{n}$$
$$-\ln(MR) = Kt^{n}$$
$$\ln(-ln(MR) = ln\ K + n.ln\ t$$
$$MR = \ln K + n.\ln t \text{ ……….Equation 5}$$

Equation 5 is in the form of a straight line. The relationship is as follows:

$$y = \mathrm{C} + m.x$$

Therefore,

$$y = MR$$
$$m = n$$
$$x = \ln t$$
$$C = \ln K$$

III. RESULTS AND DISCUSSION

A. Effect of layer thickness on drying

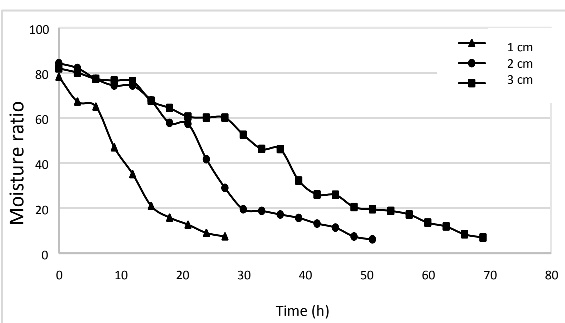

Figure 2. Effects of layer thickness on dying

The drying time increased with layer thickness of chillies. Layer thickness of 1cm took the shortest time (27 hours) and 3cm layer thickness recorded the longest time (69 hours) to reach equilibrium moisture content of 7.13%. The 2 cm layered chillies got 48 hours to reach equilibrium moisture content. This is due to the resistance to moisture movement in thicker layers than in thinner layers. This resistance is known to decrease the drying rate, which resulted in increased drying time of 3cm layer thickness chillies. This finding was in agreement with Tsegaye *et al.* (2014) who found that the layer thickness influence on drying time in drying of Arabica coffee varieties and the time duration for drying increases with the layer thickness as increased layer thicknesses maintain its moisture because of low air movement within masses of chillies that may require longer time to dry. Solomon and Behailu (2006) pointed out that in Arabica coffee for a given thickness layer, the length of the drying process depends mainly on weather conditions, degree of moisture content and size of the berries.

B. Drying constants

The Page model was fitted with the experimental data in the form of changes in moisture content versus drying time, which were calculated using Excel software. Constants were calculated by a graphical method as per equation 5 and the results of fitting are listed in Table 1.

Table 1: Drying constants of Page model for drying of chillies

Layer thickness of chilies	Page '*n*'	Page '*ln K*'
1 cm	-0.2736	2.1184
2 cm	-0.1664	1.9709
3cm	-0.1664	0.1095

C. Graphical comparisons of experimental and predicted moisture ratios

Graphical comparisons of the experimental and predicted moisture ratios from the Page Model are shown in Figures 3, 4 and 5. The closeness of the plotted data to the straight-line representing equality between the experimental and predicted values illustrates the suitability of the model for describing the drying behavior of chillies across different layers.

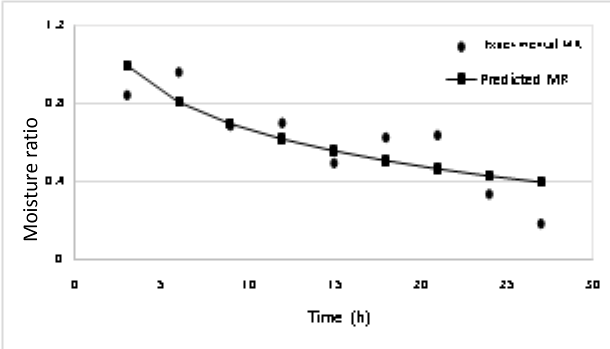

Figure 3. Experimental and predicted moisture ratios of chillies with 1 cm layer thickness.

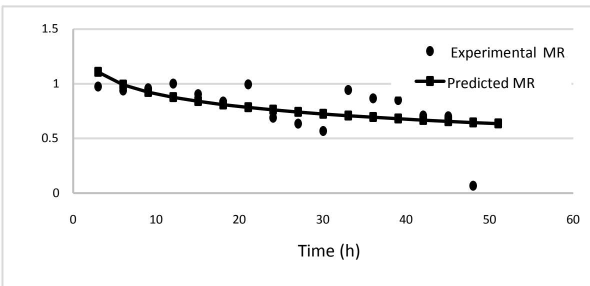

Figure 4. Experimental and predicted moisture ratios of chilies with 2 cm layer thickness.

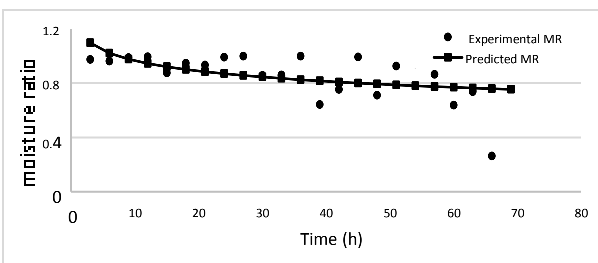

Figure 5..Experimental and predicted moisture ratios of chillies with 3 cm layer thickness

The model provided a very good conformity between the experimental data and the predicted moisture ratios of the layered chillies (1cm, 2cm and 3cm). It has been observed that the predicted data are banded around the ideal trend line indicating the suitability of the model in predicting the drying behaviour of chillies.

The summary of model parameters of the Page model used for expressing drying characteristics of different layered chillies dried in convection solar dryer and the statistical evaluation of the model using three different criteria are presented in the Tables 2. As per the procedure of Akpinar *et al*. (2006), the quality of various models was evaluated using correlation coefficient (*r*), cho-square (χ^2) and (Root Mean Square Error (*RMSE)* values.

Table 2: Results of statistical analysis of Page model

Layer thickness of chillies	χ^2	*r*	*RMSE*
1cm	0.022	0.814	0.132
2cm	1.178	0.387	1.019
3cm	0.059	0.500	0.232

The statistical analysis shows that the Page model is suitable for drying in solar dryer with different layer thicknesses as it shows best fit in solar dryer with the layer thickness of 3 cm and 1cm respectively as highest value for the correlation coefficient (*r*) and the least value for the chi-square (χ^2), and RMSE were obtained. (Table 2). The correlation coefficient in Page model shows perfect positive correlation. When comparing the layer thickness of chillies, 1 cm layered chilies show highest value of correlation coefficient. The winning model is that one whose value of χ^2 is closest to one. Here only 2 cm layered chillies drying in convective solar dryer shows the χ^2 of 1.178 in Page model.

Lower values of *RMSE* indicate better fit. According to the Table 2, the Page model shows the lower values of RMSE for all layer thickness except 2 cm layered chillies drying in convective solar dryer. Page model was also reported to fit the thin layer drying data better than other models in many earlier studies such as Akpinar *et al*. (2006) for aromatic plants, Doymaz (2004) for carrots and Hossain and Bala (2002) for green chillies. The Page model has been reported to exhibit a better fit than other models in accurately simulating the drying curves of chili (Tunde-Akintunde, 2011), (Doymaz and Pala, 2002) rape seed (Han *et al.*, 2011.), okra, (Simal *et al.*, 2005) and kiwi.

IV. CONCLUSION

The drying rate of chillies differed with the layer thickness, as drying time increased with layer thickness. The Page model showed better fit with 1cm layer thickness than 2cm and 3cm layer thicknesses during drying in natural convection solar dryer, as it showed 0.814 value of correlation co-efficient and 0.022 and 0.132 for chi square and RMSE respectively.

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