THIN LAYER DRYING OF GREEN CHILLI

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Abstract Thin layer drying experiments were conducted under controlled conditions of air temperature, relative humidity and air velocity under through flow methods of drying. The colour of dried chilli depends on drying air temperature but independent of air velocity and relative humidity. Drying air temperature of 65°C was found to be the optimum. An increase of relative humidity the drying rate of chilli decreases. The drying rate of chilli is independent of the air velocity above 0.50 m/s. The single exponential equation and the Page equation were fitted to the experimental data by direct least square procedure. The Page equation was found to describe the thin drying of green chilli better than that of the single exponential equation.

Key Words: Chilli; Thin layer drying ; Thin layer drying equations

INTRODUCTION

Theoretical, semi-theoretical and empirical equations have been developed to express and explain the thin layer drying of agricultural products. The theoretical approach concerns with either the diffusion equations or simultaneous heat and mass transfer equations. The semi-theoretical equations concern approximated theoretical equations. The empirical equations give satisfactory fit to all experimental data and take less computing time in comparison to the theoretical equations (Bala, 1997).

Several researchers (White *et al.*, 1981; Bala and Woods, 1992; Shei and Chen, 1998; Buser *et al.*, 1999) have fitted the following equation for popcorn, malt, rough rice, and marigold flower.

$$\frac{M - M_e}{M_0 - M_e} = \exp(-kt) \qquad (1)$$

Several investigators (Misra and Brooker, 1980; Bala, 1992; Liu *et al.*, 1989; Bashir, 1996; Afzal and Abe, 1999; Karathanos and Belessiotis, 1999) have reported that Page equation described below adequately predicts the thin layer drying of a wide varieties of crops such as shelled corns, malt, chilli, onion, potato, fig, currant, sultana and plums.

$$\frac{M - M_e}{M_0 - M_e} = \exp(-kt^u) \qquad (2)$$

Most of these studies have been carried out on thin layer drying of cereal grains, vegetables and fruits, but very little information is available on thin layer drying of chilli. This paper presents the laboratory experiments and equations for thin layer drying of green chilli.

MATERIALS AND METHODS

Experimental Apparatus

A thin layer drying apparatus was designed and fabricated in the Department of Farm Power and Machinery, Bangladesh Agricultural University, Mymensingh. The schematic diagram of the apparatus is shown in Fig. 1.

To dry chilli under controlled conditions of air temperature, relative humidity and air velocity, atmospheric air was supplied by a centrifugal fan, through a GI pipe, fitted with an orifice plate, to the bottom of the metal tower, packed with plastic rings. The airflow was measured with a U-tube manometer, fitted to the inlet and outlet of an orifice plate. Water was pumped from a water tank by a water pump. Water in the water tank was heated by a water heater or cooled by water cooling unit to the required dew point temperature. The temperature of the water in the water tank was controlled by a temperature controller. At the top of the tower, water was sprayed by a nozzle, at the required dew point temperature of the air. The air passing through the packed tower was approximately saturated and was exhausted from the

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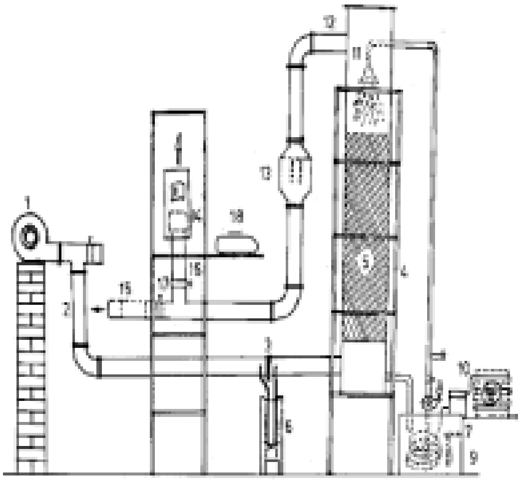


Fig. 1 Schematic view of a thin layer drying apparatus
1.blower, 2. air flow pipe, 3. orifice plate, 4. water tower, 5. plastic rings, 6.u-tube manometer, 7. water tank, 8. water pump, 9. water heater, 10. water cooling unit, 11. water spray nozzle, 12. humidified air outlet, 13. heater box, 14. through flow drying chamber, 15. overflow-underflow drying chamber, 16. through flow gate valve, 17. overflow-underflow gate valve, 18. balance

top of the water tower through GI pipe to the heater box, and was heated to the required temperature by two electric heaters. The temperature of the air in the heater box was controlled by a temperature controller. The dew point temperature of the air was measured at the exit of water bath tank using a copper-constantant thermocouple and a digital thermometer. The heated air was then passed through the GI pipe to the through flow drying chamber. In the drying chamber conditioned air passed through the tray containing chilli sample of one layer of thickness. The weight of tray containing chilli sample was weighed by an electronic balance, placed adjacent to the drying chamber.

Procedure

Thin layer drying experiments under controlled conditions of different combinations of air temperature, relative humidity and air velocity were considered and a total of 18 experimental runs were conducted. Before starting any experimental run, the instrumentation system was checked carefully. The water pump, blower, water heater or cooler, electric heater in the heater box were started simultaneously. Time required stabilizing the whole system by drying air temperature, relative humidity and air velocity was about two hours.

About 100 g of green chilli sample was blanched in hot water at 90°C for 3 minutes (FAO, 1995) and the sample was spread on a plastic filter tray to drain out excess water. After stabilizing the whole system, a sample of about 50 g of blanched chilli was placed evenly on the drying tray at single pod thickness and another 50 g sample was placed in three petridishes for moisture content determination. The initial weight of the tray with sample was recorded and the tray was placed on the seat of the drying chamber. The change of weight of the sample was recorded at 5 minutes interval. For moisture contents of the sample below 20% (db), the change in weight of the sample was recorded at 10 minutes interval. Time required for weight registration was about 10 seconds. When the weight of the sample became constant the experiment was stopped. At the completion of each experiment, the final moisture content of dried chilli sample was determined by drying the chilli sample in an air ventilated oven at 105°C temperature for 24 hours (Misra, 1972).

Colour Measurement

The chilli pods were destalked, sliced longitudinally into two halves and the seeds were removed from placenta. The sliced pods were oven dried at 58 to 60°C for two days and grounded using a grind mill equipped with a 1-mm screen. The chilli powder was sealed in plastic bags and stored at 20°C until processed. The colouring strength of chilli was determined by internationally accepted EOA (Essential Oil Association of USA) method. EOA method based on the absorbance of 0.01% w/v solution of the extractive in acetone at 458 nm and multiplied by 61000 is the EOA Colour Value (Verghese *et al*, 1992). The absorbance was measured using a UV spectrophotometer (SHIMAZU, UV-1201).

Equation Fitting

The proposed equations were fitted to the experimental data by direct least square using Davidon-Fletcher-Powell method (Bala, 1997). The fitting of the equation was evaluated on the basis of goodness of fit by the coefficient of determination and root mean square error.

RESULTS AND DISCUSSION

Effect of Temperature

The effect of temperature on thin layer drying of green chilli at 20% relative humidity and 0.50 m/s air velocity is shown in Fig. 2. Drying rate increases with the increase in drying air temperature.

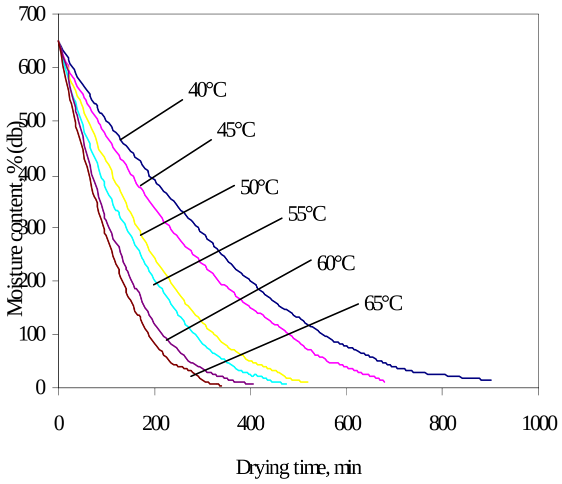
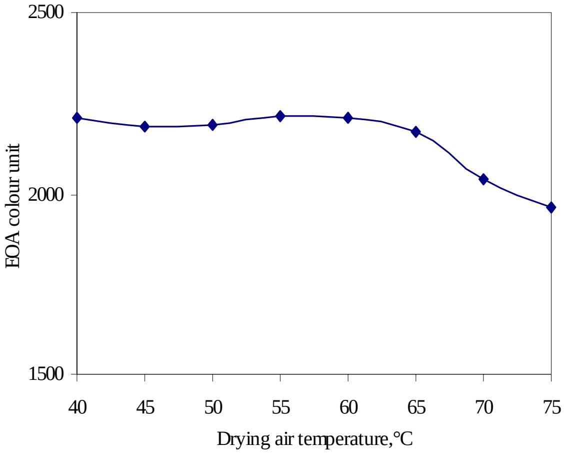


Fig. 2 Thin layer drying of green chilli at different air temperature (rh=20% and v=0.50 m/s)

The effect of drying air temperature on colour of green chilli is shown in Fig. 3. An increase of drying air temperature from 40 to 65°C, the colour unit remains almost constant and above drying air temperature 65°C, the colour unit decreases. Hence, air temperature of 65°C found to be the optimum for drying of chilli.



Effect of drying air temperature on colour of green (rh=20% and v=0.50 m/s)

fig.

Effect of Relative Humidity

The effect of relative humidity on thin layer drying of green chilli at 60°C temperature and 0.50 m/s velocity is shown in Fig. 4. Drying rate of chilli is higher at lower relative humidity and decreases with the increase in relative humidity. There is no effect of relative humidity on colour of dried chilli. Drying time increases from 8.25 to 15.42 hours as relative humidity increases from 10 to 60%.

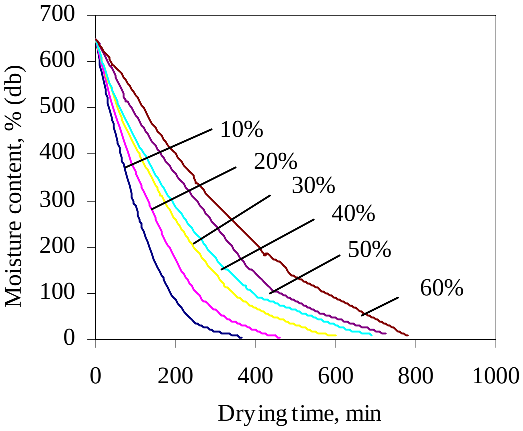


Fig. 4 Thin layer drying of green chilli at different relative humidity (T=60°C and v=0.50 m/s)

Effect of Air Velocity

The effect of air velocity on thin layer drying of green chilli at 60°C temperature and 20% relative humidity is shown in Fig. 5. Drying rate increases with the increase of air velocity up to 0.50 m/s. Drying rate become independent of air velocity above air velocity 0.50 m/s. Colour of dried chilli is also independent of air velocity.

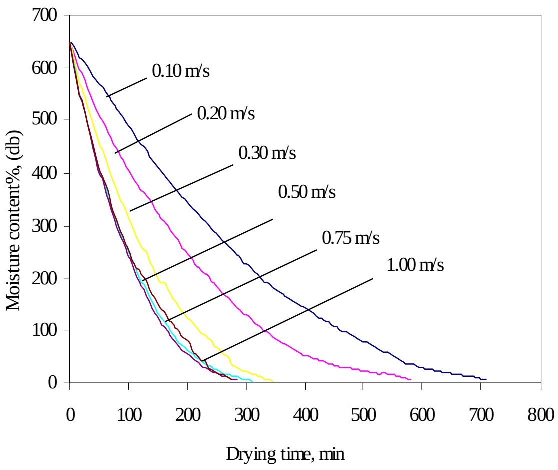


Fig. 5 Thin layer drying of green chilli at different air velocity (T=60°C and rh=20%)

Fitting of Equations to Experimental Data

The mean parameters, coefficients of determination and root mean square errors of the single exponential equation and the Page equation are shown in Table 1. The mean values of coefficients of determination were higher than 0.99 for both the single exponential equation and the Page equation of all experimental runs. The fits of the single exponential equation and the Page equation were good with the experimental data. The mean root mean square error of the Page equation was found to be lower than the single exponential equation.

Table-1: Estimated mean values of parameters, coefficient of determination (R^2) and root mean square error (RMSE) of the single exponential equation and the Page equation

Equa-tion	k (min^{-1})	u	M_e (%)	M_o-M_e (%)	R^2	RMSE
Single	0.0047		-0.9600	751.16	0.9991	0.0762
Page	0.0014	1.135	-0.9119	733.59	0.9995	0.0521

The dynamic equilibrium moisture content was estimated by the best fitting of the single exponential equation and the Page equation to the experimental data by direct least square method. The mean values of estimated dynamic equilibrium moisture content obtained from the best fitting of the single exponential equation and the Page equation to experimental data are given in Table 1. The estimated dynamic equilibrium moisture content was found to be very low and negative. The dynamic equilibrium moisture content is a hypothetical concept. It is obtained by the best fitting of the thin layer drying equation to the experimental data and hence it can be negative for the best fit of the experimental data to the proposed equation. The concept of dynamic equilibrium moisture content has been criticized by some researchers because of the physical non-existence of such moisture content (Chu and Hustrulid, 1968). But the dynamic equilibrium moisture content gives better estimates of drying rate and better description of drying behaviour than those of static equilibrium moisture content. Again, in this case the equations did not fit well to the experimental data of thin layer using static equilibrium moisture content.

Development of Model

Drying rate constant (k), M_e and M_o-M_e of the single exponential equation were found to be a function of air temperature, relative humidity and air velocity. The following equations were developed for k, M_e and M_o-M_e of the single exponential equation.

$$k = -6.84593 + 0.148624\,\mathrm{T} - 0.00102\,\mathrm{T}^2 + 0.32091\psi - 2.7198\psi^2 + 3.30269\,\mathrm{V} - 2.62254\mathrm{v}^2 \qquad (3)$$

$$M_e = -6.84593 + 0.148624\,\mathrm{T} - 0.00102\,\mathrm{T}^2 + 0.3209\psi - 2.7198\psi^2 + 3.30269\,\mathrm{V} - 2.62254\mathrm{V}^2 \qquad (4)$$

$$M_o - M_e = 14.8445 - 0.18331\,\mathrm{T} + 0.001388\,\mathrm{T}^2 - 8.13163\psi + 15.27832\psi^2 - 2.14959\,\mathrm{V} + 1.7514\mathrm{v}^2 \qquad (5)$$

Drying rate constant (k), exponent (u), M_e and M_o-M_e of the Page equation were found to be a function of air temperature, relative humidity and air velocity. The following equations were developed for k, u, M_e and M_o-M_e of the Page equation.

$$k = -0.02184 + 0.000781\,\mathrm{T} - 6.80\times10^{-6}\,\mathrm{T}^2 + 0.004437\psi - 0.01335\psi^2 + 0.004522\mathrm{V} \qquad (6)$$

$$u = 0.580425 + 0.00465\,\mathrm{T} - 1.2421\psi + 1.38450\psi^2 + 1.7177\mathrm{V} - 1.2991\mathrm{V}^2 \qquad (7)$$

$$M_e = -1.35338 + 0.020726\,\mathrm{T} - 1.62963\psi + 1.8798\psi^2 + 1.204856\mathrm{V} - 1.161\mathrm{V}^2 \qquad (8)$$

$$M_o - M_e = 8.97083 - 0.02159\,\mathrm{T} + 1.50562\psi - 1.2773\psi^2 - 4.6066\mathrm{V} + 3.539476\mathrm{V}^2 \qquad (9)$$

Validity of the Models

The mean values of coefficient of determination and root mean square errors of the observed and predicted moisture content using the single exponential equation and the Page are given in Table 2. It is observed from the tabulated results that high coefficients of determination (R^2>0.99) were obtained between the observed and the predicted moisture contents using the single exponential equation and the Page equation. Hence, the overall agreements between the observed and the predicted moisture contents using the single exponential equation and the Page equation are good.

Table-2: Mean values of coefficient of determination (R^2) and root mean square error (RMSE) of the observed and predicted moisture content for fitting single exponential equation and Page equation to the experimental data

Single exponential equation		Page equation	
R^2	RMSE (decimal)	R^2	RMSE (decimal)
0.9952	0.11029	0.9970	0.09314
0.9913	0.15336	0.9967	0.10325

The mean coefficient of determination of single exponential equation and the Page equation are almost same. But root mean square error of the Page equation are found to be lower than that of the single exponential equation. Hence, the over all fitting of the Page equation was better than that of the single exponential equation.

The predicted and observed values by the Page equation and the single exponential equation for a typical experimental run are shown in Figs. 6 and 7. Agreements between the prediction by the Page equation and experimental data were excellent. The overall fitting of the Page equation was slightly better than the single exponential equation.

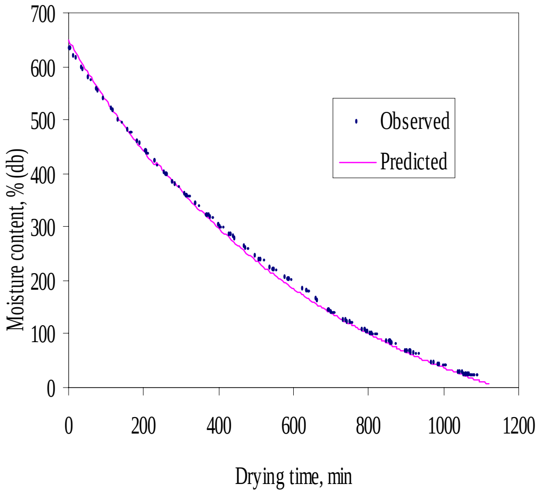


Fig.6 Observed and predicted moisture content of thin layer drying of green chilli of run-1 (T=40°C, rh=20%, v=0.50 m/s) using the single exponential equation

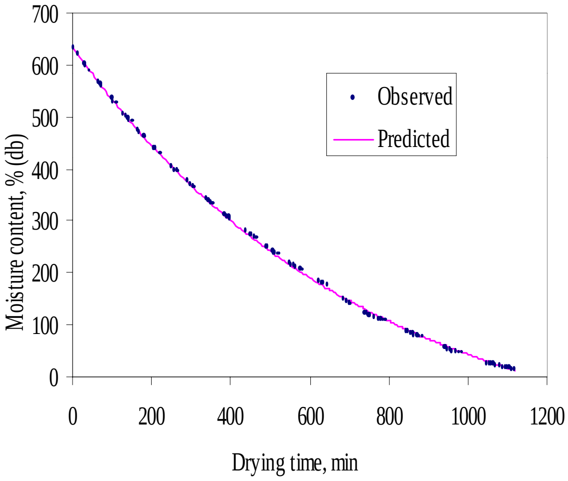


Fig. 7 Observed and predicted moisture content of thin layer drying of green chilli of run-1 (T=40°C, rh=20%, v=0.50 m/s) using the Page equation

CONCLUSIONS

Drying rate of green chilli increases with the increase of air temperature and it decreases with the increase of relative humidity. Drying rate also increase with the increase of air velocity up to 0.50 m/s and drying rate is independent of air velocity above 0.50 m/s. The colour of dried chilli depends on drying air temperature but independent of air velocity and relative humidity. Drying air temperature of 65°C was found to be the optimum. The parameters of the single exponential and the Page equation were found to be a function of air temperature, relative humidity and air velocity. Both the equations fitted well to the experimental data. The Page equation was found to describe the thin layer drying of chilli slightly better than that of the single exponential equation.

NOMENCLATURE

k	drying rate constant, min^{-1}
M	moisture content, decimal
M_e	dynamic equilibrium moisture content, %
M_o	initial moisture content, decimal
R^2	coefficient of determination
RMSE	root mean square error, decimal
T	air temperature, °C
t	drying time, min
u	exponent of the Page equation
V	air velocity, m/s
ψ	relative humidity, decimal

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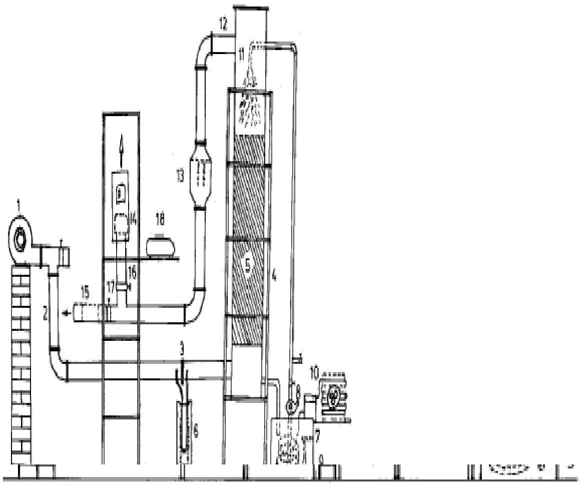
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