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Thin layer drying of long pepper (*Piper longum* L.)

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Abstract

The effect of drying air temperatures on the drying kinetics of long pepper was investigated during 2010 using a hot-air tray dryer. In order to select the appropriate drying model, twelve mathematical drying models were fitted to the experimental data. Result indicated that the drying took place in the falling rate period. Considering the statistical criteria such as coefficient of determination (R^2), Chi square (X^2), sum of square error (SSE) and root mean square error (RMSE), Midilli *et al.* model was found to fit well to describe the drying behaviour of long pepper. Multiple regression analysis was used to find the correlation of the model coefficients with temperatures. Model coefficient equations predicted the moisture ratio (MR) well at various drying temperatures for long pepper with an R^2=1 and SE=0. Effective moisture diffusivity (D_{eff}) was observed in the range of 1.397×10^{-10} to 6.190×10^{-10} m^2s^{-1} for the temperature range of 40° to 80°C. The overall acceptability (OA) (90%) was highest in tray drying method at 60°C air temperature and the drying time was reduced to 50% against sun drying. This study will be useful to optimize drying process parameters for commercial production of dried long pepper.

Keywords: long pepper, mathematical modeling, *Piper longum*, tray drying, value addition

Introduction

Long pepper (*Piper longum* L.) is one of the most important medicinal plants in India especially in Assam, lower hills of Bengal, evergreen forests of Western Ghats from Konkan to Travancore, Maharashtra, Andhra Pradesh, Uttar Pradesh, Tamil Nadu and Kerala. Also it is largely consumed as a spice. Fresh long pepper is perishable due to its high moisture content. Therefore, drying removes the moisture content and preserves long pepper for longer periods of time. The most common drying method is open air-sun drying, which is used for drying of medicinal plants, spices, vegetables and fruits. There are many problems associated with sun drying method, such as lack of sufficient control during drying, being extremely weather dependent, contamination with dust, soil and insects and undesirable changes in the quality of products. These problems could be overcome if mechanical dryers are used.

Modeling of drying processes and kinetics is a tool for process control and is necessary to chooses suitable method of drying for a specific product. Thin-layer drying models have been used to describe the drying process of several agricultural products and medicinal plants such as red pepper (Doymaz & Pala 2002), black pepper (Joy *et al.* 2002) and *Aloe vera* (Gulia *et al.* 2010). The solution of Fick's second law was used in thin layer drying of mint leaves (Doymaz 2006; Kadam *et al.* 2011). The aim of the present work was to investigate the thin-layer convective drying behaviour of long pepper.

Materials and methods

The experiment was conducted at Department of Agricultural Process Engineering, Dr. Punjabrao Deshmukh Krishi Vidyapeeth, Akola during November to January 2010. Long pepper samples used in this study were obtained from Panweli Research Station, Akot, District Akola, Maharashtra. The first harvest from vines was done after six months of planting. The spikes were harvested two months after their formation when they are blackish green colour and most pungent. Harvest was done early in the morning. The harvested spike was washed with water to remove adhering impurities and pretreated with 0.5% potassium metabisulphite to improve the colour and control microbial and insect infestation during processing. The moisture content (MC) of the sample was determined using hot air oven (0 to 300°C). The weighed samples (10 to 12 g) were subjected to remove moisture at 105 ± 2°C for 24 h (AOAC 2000). All values reported are mean of four replications.

The MC was determined on wet weight basis (wb) by using following formula

$$MC\ (\%) = (W_1 - W_2)/\ (W_1 - W_3) \quad (1)$$

Where, W_1=Initial weight of the test sample (g); W_2=Final weight of the test sample (g); W_3=Weight of petridish (g)

The MC obtained in % on wb was converted into %, dry weight basis (db) by using the following formula

$$MC\ (\%) = [MC\ (wb)/\ 100\text{-}MC\ (wb)] \times 100 \quad (2)$$

Drying equipment

Drying was performed in a hot air tray dryer. The dryer mainly consisted of three basic units, namely, air supply unit, electrical heaters controlling the temperature of drying air and drying chamber. There were 12 trays in the dryer with three heaters of 1000 W capacity and the dial thermometer of temperature range 0 to 200°C was installed. The air velocity (0.8 m s^{-1}) circulated inside the dryer was constant throughout the experiment in tray dryer.

Experimental procedure

Experiments were performed at air temperatures of 40°, 60° and 80°C in tray dryer and compared with sun drying. Each experiment was repeated three times. The dryer was operated under unloaded condition for about 30 min to achieve a steady state condition. Then the samples (about 100 g) were put on the tray in single layer. The weight loss was measured by weighing balance. The weight loss of the samples was recorded at every 30 minutes interval. Drying time was defined as the time required to reduce the moisture content of long pepper.

Mathematical modeling of the drying curves

In this study, mathematical models were used to describe the drying kinetics of long pepper. The drying curves plotted were fitted with 12 different moisture ratio models (Table 1). However, the dimensionless moisture ratio (MR) was simplified to M/M_0 instead of $(M\text{-}M_e)(M_0\text{-}M_e)^{-1}$ for long drying time, because the values of the M_e are relatively small as compared to M or M_0. Hence, the error involved in the simplification is negligible (Togrul & Pehlivan, 2004).

The non-linear least square regression analysis based on STATISTICA 8 was used to estimate the parameters of the models (by fitting the model equations to experimental data). The coefficient of determination (R^2), chi square (χ^2) sum of square error (SSE) and the root mean square error (RMSE) were used as criteria for verifying the goodness of fit (Togrul 2005; Sacilik & Elicin 2006). The best model for describing the thin-layer drying characteristics

Table 1. Thin-layer mathematical drying models

Model	Mathematical equation	Reference
Newton	$MR=\exp(-kt)$	Midilli (2001)
Page	$MR=\exp(-kt^n)$	Midilli (2001)
Henderson & Pabis	$MR=a\exp(-kt)$	Yaldiz *et al.* (2001)
Modified Henderson & Pabis	$MR=a\exp(-kt)+b\exp(-k_0t)+c\exp(-k_1t)$	Karathanos (1999)
Logarithmic	$MR=a\exp(-kt)+c$	Togrul & Pehlivan (2004)
Two term	$MR=a\exp(-k_0t)+b\exp(-k_1t)$	Midilli (2001)
Two term exponential	$MR=a\exp(-kt)+(1-a)\exp(-kat)$	Midilli (2001)
Verma *et al.*	$MR=a\exp(-kt)+(1-a)\exp(-gt)$	Verma *et al.* (1985)
Diffusion approach	$MR=a\exp(-kt^n)+(1-a)\exp(-kbt)$	Yaldiz *et al.* (2001)
Midilli *et al.*	$MR=a\exp(-kt^n)+bt$	Midilli *et al.* (2002)
Magee	$MR=a+kt^{1/2}$	Magee *et al.* (1983)
Wang & Singh	$MR=1+at+bt^2$	Wang & Singh (1978)

of long pepper was chosen as the one with the highest value of R^2 and the least values of χ^2 and RMSE (Togrul 2005). Then the relationships between coefficients of the best model and the drying variables were determined using multiple regression analysis. All possible combinations of the different drying variables were tested and included in the regression analysis (Togrul 2005).

Moisture diffusivity

Fick's diffusion equation for particles with slab geometry was used to calculate the moisture diffusivity. For the determination of moisture diffusivity, long pepper was considered as having slab geometry (Doymaz 2006). The equation for moisture diffusivity is expressed by (Crank 1975).

$$D_{eff} = \ln MR - \ln \frac{8}{\pi^2} \Big/ \frac{\pi^2 t}{4L^2} \tag{3}$$

The slope was calculated by plotting ln (MR) versus time to determine the effective diffusivity for different temperatures.

$$K_O = \pi^2 D_{eff} / 4L^2 \tag{4}$$

Sensory evaluation

Dried pepper was obtained from different methods i.e. sun and tray dried samples were served for sensory evaluation by a panel of 10 semi trained judges according to nine point hedonic scale. The average score of 10 judges for different quality characteristics *viz*., colour, texture and overall acceptability was recorded.

Results and discussion

Drying curves

The initial moisture content of long pepper was found to be 400% (db). The moisture content versus drying time and the variation of drying rate with moisture content at various air temperatures indicated that moisture content decreased exponentially with drying time (Fig. 1). Similar results were reported for

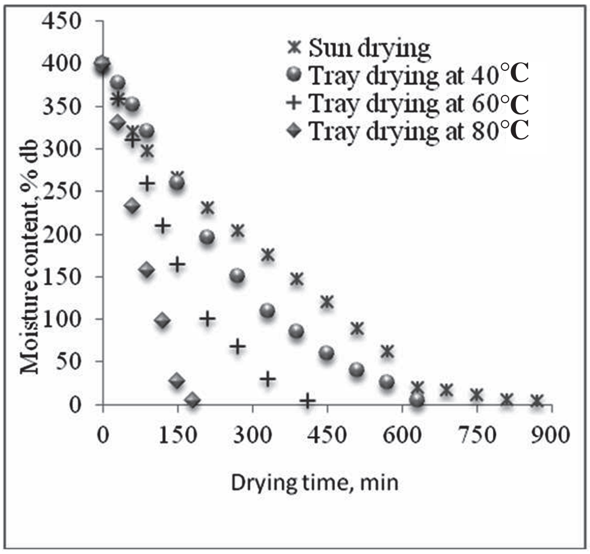

Fig. 1. Drying curve for long pepper at different temperatures

drumstick leaves (Premi *et al.* 2010) and bay leaves (Demir *et al.* 2004). Increase in the air temperature reduced the time required to reach a certain level of moisture content and drying time. The drying time required to reduce the moisture content from initial moisture content of 400% to final moisture content in the range of 5.0% to 6.7% were 870, 610, 410 and 180 min by sun drying (34°-37°C), 40°, 60° and 80°C in a hot air tray dryer, respectively. The drying time was reduced to nearly 50% and 80% in tray drying at 60°C and 80°C, respectively over sun drying. The analysis of variance indicated that the air temperature had a significant effect on the drying time (P d” 0.0001). Similar results were reported for drying of apple (Sacilik & Elicin 2006) and for mint leaves (Kadam *et al.* 2011).

The drying rate decreased continuously with decreasing moisture content (Fig. 2). In this curve, a constant drying rate period was not observed and drying process occurred in the falling rate period only and the diffusion mechanism controlled moisture movement. These results are in agreement with the results on drying of apple (Togrul 2005; Sacilik & Elicin 2006). When the temperature increased from sun drying (34°–37°C) to 80°C, the drying rate almost doubled. The drying rate increased with increasing drying air temperature and consequently decreased the drying time. It is a fact that the higher temperature difference between the drying air and long pepper increased the heat transfer coefficient, which influenced the heat and mass transfer rate. The results for drying of apple (Sacilik & Elicin 2006) and for mint leaves (Kadam *et al.* 2011) also support our finding.

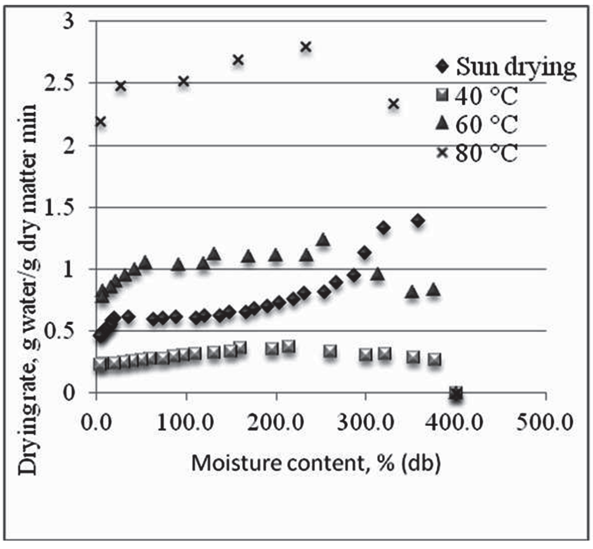

Fig. 2. Drying rate vs moisture content of long pepper at different temperatures

Modeling of drying curves

The moisture content data obtained at different air temperatures were converted to dimensionless moisture ratio (MR) and then fitted in 12 drying models (Table 1). Twelve thin layer drying models were evaluated according to the statistical criteria, R^2, X^2, SSE and RMSE (Table 2) and the Midilli *et al.* (2002) model was selected as the suitable model to represent the thin layer drying behaviour of long pepper. This model provided a good agreement between experimental and predicted moisture ratios (Table 1 and Fig. 3).

The drying curves for long pepper at different air temperatures were obtained by taking into account the effect of drying air temperature on the coefficients of selected Midilli *et al.* (2002) model. The values of coefficients were regressed against drying-air conditions using multiple regressions. The multiple combinations of different parameters, which gave the highest R^2 value, were finally included in the selected model.

The coefficients of Midilli *et al.* (2002) model for the convective drying using hot air tray dryer

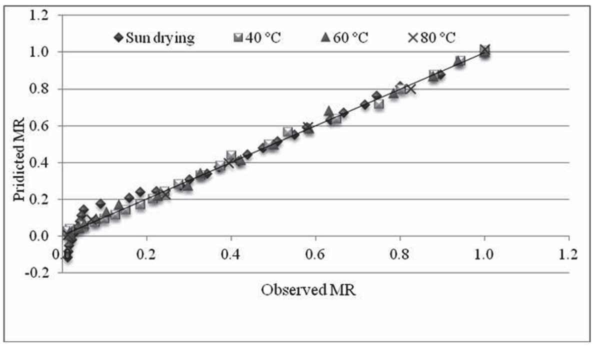

Fig. 3. Observed vs predicted values of moisture ratio using the Midilli *et al*. model for different temperatures

Table 2. Results of statistical analysis of twelve thin layer drying models

Model	Drying method	Drying temperature (°C)	R^2	χ^2	SSE	RMSE
Newton	Sun	34-37	0.960	0.004	0.105	0.011
	Tray	40	0.969	0.003	0.066	0.012
	Tray	60	0.948	0.006	0.102	0.012
	Tray	80	0.945	0.008	0.046	0.031
Page	Sun	34-37	0.990	0.001	0.009	0.006
	Tray	40	0.997	0.000	0.007	0.004
	Tray	60	0.996	0.001	0.009	0.005
	Tray	80	0.994	0.001	0.005	0.010
Henderson & Pabis	Sun	34-37	0.961	0.004	0.102	0.011
	Tray	40	0.981	0.002	0.041	0.011
	Tray	60	0.964	0.004	0.070	0.015
	Tray	80	0.953	0.006	0.040	0.028
Modified Henderson & Pabis	Sun	34-37	0.999	0.002	0.001	0.008
	Tray	40	0.998	0.000	0.004	0.003
	Tray	60	0.992	0.001	0.016	0.007
	Tray	80	0.995	0.001	0.004	0.009
Logarithmic	Sun	34-37	0.992	0.001	0.006	0.005
	Tray	40	0.990	0.006	0.123	0.016
	Tray	60	0.991	0.001	0.018	0.007
	Tray	80	0.995	0.001	0.004	0.009
Two term	Sun	34-37	0.995	0.002	0.004	0.009
	Tray	40	0.995	0.000	0.010	0.005
	Tray	60	0.994	0.001	0.012	0.006
	Tray	80	0.995	0.001	0.004	0.009
Two term Exponential	Sun	34-37	0.988	0.001	0.010	0.003
	Tray	40	0.998	0.000	0.003	0.003
	Tray	60	0.930	0.008	0.041	0.021
	Tray	80	0.989	0.002	0.010	0.014
Verma	Sun	34-37	0.992	0.003	0.006	0.009
	Tray	40	0.993	0.001	0.015	0.006
	Tray	60	0.977	0.003	0.045	0.012
	Tray	80	0.981	0.003	0.016	0.018
Diffusion approach	Sun	34-37	0.988	0.001	0.031	0.006
	Tray	40	0.993	0.001	0.015	0.006
	Tray	60	0.994	0.001	0.012	0.006
	Tray	80	0.990	0.001	0.008	0.013
Midilli *et al.*	Sun	34-37	0.998	0.002	0.001	0.008
	Tray	40	0.998	0.000	0.005	0.003
	Tray	60	0.997	0.000	0.005	0.004
	Tray	80	0.998	0.000	0.002	0.006
Magee	Sun	34-37	0.980	0.002	0.052	0.008
	Tray	40	0.971	0.003	0.062	0.011
	Tray	60	0.958	0.005	0.082	0.016
	Tray	80	0.942	0.008	0.049	0.031
Wang & Singh	Sun	34-37	0.988	0.001	0.031	0.006
	Tray	40	0.994	0.001	0.012	0.005
	Tray	60	0.991	0.001	0.017	0.007
	Tray	80	0.995	0.001	0.004	0.009

Table 3. Coefficients of the Midilli *et al.* model at different drying conditions

Temperature (°C)	Coefficients			
	a	K	n	B
34-37 (Sun)	1.002	0.019	0.505	-0.001
40	1.009	0.001	1.269	-0.000
60	0.996	0.000	1.474	-0.000
80	1.014	0.000	3.160	-0.007

of long pepper were determined by following equations. The coefficient depends on drying air temperature.

$MR = a \exp(-kt^n) + bt$ (5)

where, $a=0.009T^3 - 0.061T^2 + 0.129T + 0.925$

$k=-0.003T^3 + 0.027T^2 - 0.079T + 0.074$

$n=0.173T^3 - 1.320T^2 + 3.509T - 1.858$

$b=-0.001T^3 + 0.006T^2 - 0.010T + 0.004$

The above four equations predicted the moisture ratio (MR) well at four drying temperature 34°–37°C (sun drying), 40°, 60° and 80°C for the long pepper with an R^2=1 and SE=0.

Moisture diffusivity

Moisture diffusivity of long pepper increased with increase in drying air temperature. Moisture diffusivity (D_{eff}) varied from 1.3969 × 10^{-10} to 6.1902 × 10^{-10} m^2s^{-1} for temperature range from 40° to 80°C. These values are within the range 10^{-9} to 10^{-11} m^2s^{-1} for drying of food materials (Kadam *et al*. 2011). The linear relationship between ln (MR) and time with R^2 values are presented in Table 4 and the relationship between ln (MR) and time are shown in Fig. 4 for various drying air temperatures of long pepper.

Sensory evaluation

The average score of 10 judges for different quality characteristics *viz*., smell, colour, texture and overall acceptability was recorded. The overall acceptability of all samples was found to be in the range of 70% to 90% but colour of tray dried sample at 80°C temperature was dark and not acceptable (Table 5). The sample prepared by using tray drying at 40° and 60°C air temperatures was found to have the maximum overall acceptability of 89.88% and 90%, respectively.

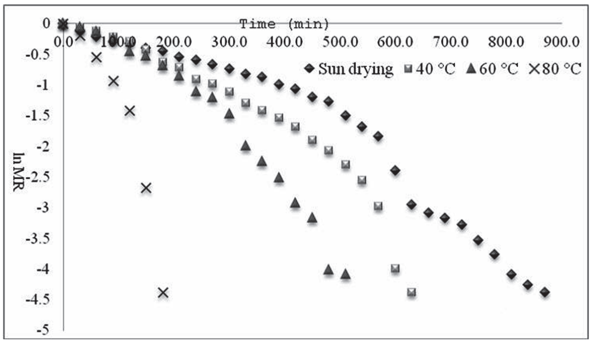

Fig. 4. Moisture ratio vs drying time during drying of long pepper at different temperatures

The drying behaviour of the long pepper was investigated in a thin layer hot-air dryer at air temperatures of 34° to 37°C in sun drying and 40°, 60° and 80°C in tray drying. The drying of long pepper occurred in the falling rate period and the diffusion mechanism controlled moisture movement. Drying air temperature affected the drying rate and time. The minimum drying time was found to be 180 min in tray drying at 80°C temperature. The drying rate increased with increase in the drying-air temperature. Midilli *et al.* (2002) model was adequate for describing the thin-layer drying behaviour of pepper. The drying parameters a, k, n and b in Midilli *et al.* (2002) model can be expressed as a linear function of the temperature with an R^2 value of 1 and SE of 0. Effective moisture diffusivity was observed to

Table 4. Moisture diffusivity and its linear equation at different drying temperatures for long pepper

Drying temperature (°C)	Equation	k_o	D_{eff}	R^2
Sun drying	MR= – 0.005t + 0.546	-0.005	1.397 × 10^{-10}	R^2=0.921
40	MR= – 0.006t + 0.447	-0.006	1.643 × 10^{-10}	R^2=0.901
60	MR= – 0.008t + 0.538	-0.008	2.246 × 10^{-10}	R^2=0.941
80	MR= – 0.023t + 0.586	-0.023	6.190 × 10^{-10}	R^2=0.865

Table 5. Sensory evaluation of long pepper

Sl. No	Sample	Smell	Colour	Texture	Overall Acceptability	Overall Acceptability (%)
1	Sun	7.33	7.33	5.66	6.77	75.26
2	40°C	8.15	8.00	8.12	8.09	89.89
3	60°C	8.07	8.00	8.26	8.11	90.11
4	80°C	6.33	6.09	7.90	6.77	75.25

increase with increase in drying air temperatures. The drying time of 410 min was found in tray dried method at 60°C air temperature.

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