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Development of thin layer model for sun drying characteristics of black pepper (*Piper nigrum*)

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Abstract
The sun drying characteristics of two varieties of black pepper *viz.* Sreekara and Panniyur-1 was studied. The drying process took place in the falling rate period. Sreekara took 38 h to dry from initial moisture content of 244.82% dry basis (d.b.) to the final moisture content of around 9.77% d.b. Whereas Panniyur-1 took 40 h to dry from initial moisture content of around 270.37 % d.b. to the final moisture content of around 9.63% d.b. The drying data were fitted to eight different mathematical models. The performance of these models was investigated by comparing the coefficient of determination (r^2), root mean square error (RMSE), mean bias error (MBE) and mean square of deviation (χ^2) between the observed and predicted moisture ratios. Among the models, the diffusion approximation model was found most suitable to explain the thin layer open sun drying behaviour of black pepper. The effective moisture diffusivity during drying of black pepper was 4.13 x 10^{-07} m^2s^{-1} for Sreekara and 4.90 x 10^{-07} m^2s^{-1} for Panniyur-1.

Keywords: Black pepper, sun drying, thin layer modeling, diffusivity, diffusion model

Introduction

Drying is the process of moisture removal due to simultaneous heat and mass transfer. It is also a method of food preservation, which provides longer shelf-life, lighter weight for transportation and smaller space for storage. Natural sun drying is still widely practiced in many places throughout the world where solar radiation is sufficient (Togrul and Pehlivan, 2004) [28].

Black pepper is the whole dried fruit of the vine *Piper nigrum*. Harvesting is done when the berries are fully mature and few starts turning from yellow to red in each spike. At harvest the berries have moisture content of about 70 %. It is important to dry the berries as quickly as possible to prevent mould contamination and microbial growth. The berries are then spread on clean dry concrete floor and dried in the sun for a period of 4 - 6 days to bring the moisture content to 8-10 % (Pruthi, 1993) [24].

Simulation models are helpful in designing new or in improving existing drying systems or for the control of the drying operation. The drying kinetics of materials may be described completely using their transport properties (thermal conductivity, thermal diffusivity, moisture diffusivity, and interface heat and mass transfer coefficients) together with these of the drying medium (Vagenas and Karathanos, 1993) [29]. In the case of food drying, the drying constant K is used instead of transport properties. The drying constant combines all the transport properties and may be defined by the thin layer equation.

Thin layer equations describe the drying phenomena in a unified way, regardless of the controlling mechanism. They have been used to estimate drying times of several products and to generalise drying curves. In the development of thin layer drying models for agricultural products, generally the moisture content of the material at any time after it has been subjected to a constant relative humidity and temperature conditions is measured and correlated to the drying parameters (Midilli *et al.*, 2002) [22]. Several thin layer equations have been used successfully to explain sun drying characteristics of several agricultural products. For example apricot (Togrul and Pehlivan, 2002) [26], mulberry fruits (Doymaz, 2004b) [10], apricots, grapes, figs and plums (Togrul and Pehlivan 2004)[28], parsley leaves (Akpinar *et al.*, 2006)[2], parsley, mint and basil (Akpinar, 2006) [1] strawberry (Beltagy *et al.* 2007) [5]. The objectives of this paper is to study the sun drying behavior of black pepper and to fit drying data into the most suitable models by appropriate statistical analyses procedures.

Materials and methods

Sun drying experiments were conducted during January 2006. Two varieties of black pepper i.e., Sreekara and Panniyur-1 were collected from the ICAR-Indian Institute of Spices Research, Experimental farm at Peruvannamuzhi, Kozhikode. Each pepper variety of black pepper (4 kg) was spread in thin layers on concrete floors and dried under sun. The weight loss of pepper was recorded continuously for every two hours till the material attained a constant mass. The experiment was repeated three times.

Mathematical modeling of drying curves

The moisture content data during drying were converted into moisture ratio and expressed by the following equation (Hayaloglu *et al.*, 2007) [17]:

$$MR = \frac{M - M_e}{M_o - M_e} \tag{1}$$

For long drying periods, the relative humidity of the drying air fluctuated continuously under open-air sun drying conditions and hence the moisture ratio could be simplified (Diamante and Munro, (1991)[7], Yaldız & Ertekin, (2001)[30]) to:

$$MR = \frac{M}{M_0} \tag{2}$$

where, MR is the moisture ratio, M_0 is the initial moisture content in % d.b., M is the moisture at time t in % d.b., M_e is the equilibrium moisture content in % d.b.. The moisture content data were converted into moisture ratio (MR) expression and curve fitting with drying time were carried for 8 drying models (Table 1). The highest value of coefficient of determination (r^2) and the lowest values of root mean square error (RMSE) mean bias error (MBE) and mean square of deviation (χ^2) were used to determine the best fit of the drying models (Togrul and Pehlivan, (2002) [26], Ertekin and Yaldiz, (2004) [15], Akpinar, (2006) [1].

The statistical parameters were calculated as follows:

$$\chi^2 = \frac{\sum_{i=1}^{N}\left(MR_{\exp,i} - MR_{pre,i}\right)^2}{N - n} \tag{3}$$

$$RMSE = \left[\frac{1}{N}\sum_{i=1}^{N}\left(MR_{\exp,i} - MR_{pre,i}\right)^2\right]^{\frac{1}{2}} \tag{4}$$

$$MBE = \frac{1}{N}\sum_{i=1}^{N}\left(MR_{\exp,i} - MR_{pre,i}\right) \tag{5}$$

Where, $MR_{\exp,i}$ is the i^{th} experimentally observed moisture ratio, $MR_{pre,i}$ i^{th} predicted moisture ratio, N is the number of observations and n is the number of constants in the model. The parameters of all the models were estimated by using Sigma Plot 8.0 statistical software.

Determination of effective moisture diffusivity

Transport of water in food material is an important physical process. Water is transported with in the food materials by a combination of several mechanisms depending on the physical structure of the product and external drying conditions. The prevalent mechanisms are molecular diffusion and capillary flow. Molecular diffusion is used widely for estimation of effective moisture diffusivity of foods although water may be transported by mechanisms other than diffusion. It is assumed that the driving force for all water transport is the moisture gradient. Fick's second law was used to describe the moisture diffusion during drying of spherical objects as follows (Crank, 1975) [6]:

$$MR = \frac{M - M_e}{M_o - M_e} = \frac{M}{M_o} = \frac{6}{\pi^2}\left[\sum_{n=1}^{n=\infty}\frac{1}{n^2}\exp\left(\frac{-n^2\pi^2}{6}\frac{D_{eff}\,t}{R^2}\right)\right] \tag{6}$$

where MR is the moisture ratio, M_0 is initial moisture content in % d.b, M is moisture content at time t in % d.b, M_e is equilibrium moisture content in % d.b, D_{eff} is effective moisture diffusivity in m^2h^{-1}, t is the drying time in h and R is the thickness of spherical pepper to be dried from top and bottom parallel surfaces in m.

For long drying periods, Eq. (6) can be simplified to the following form by taking n=0 (Geankoplis, 2003) [16].

$$MR = \frac{M}{M_o} = \frac{6}{\pi^2}\exp\left(\frac{-\pi^2}{6}\frac{D_{eff}\,t}{R^2}\right) \tag{7}$$

The above equation is in the form of

$$MR = \frac{M}{M_o} = Ae^{-kt} \tag{8}$$

Where, the constant $A = \frac{6}{\pi^2}$; and $k = \frac{\pi^2 D_{eff}}{6R^2}$. By linearizing the Eq. (8)

$$\ln(MR) = \ln\left(\frac{M}{M_o}\right) = \ln A - kt \tag{9}$$

The effective moisture diffusivity of black pepper can be calculated using the method of slopes. A plot of ln (M/ M_0) versus drying time gives a straight line with a slope. Assuming that drying occurs from top and bottom parallel faces, thickness of the sphere to be dried from one face is assumed to be half the total thickness, where R = R/2 in m. Hence the slope is taken as:

$$\text{Slope} = k = \frac{2\pi^2 D_{eff}}{3R^2} \tag{10}$$

From Eq. (10) the effective moisture diffusivity D_{eff} can be calculated.

Results and Discussion

During the open sun drying experiments, the average ambient air maximum and minimum temperatures were 34 °C and 19.5 °C. The mean relative humidity was 64.3%.

Drying kinetics

Drying characteristic curves of black pepper are presented in Fig.1. It is apparent that moisture content decreases continuously with drying time. The time required to dry Panniyur-1 black pepper from an initial moisture content of around 270.37 % d.b. to the final moisture content of around 9.63 % d.b. was 40 h. Whereas for drying Sreekara from an initial moisture content of around 244.82 % d.b. to the final moisture content of around 9.77 % d.b. the time taken was 38 h. Curves of moisture ratio versus drying time for drying black pepper showed that moisture ratio of black pepper reduced exponentially as the drying time increased.

As indicated in the curves of drying rate verses time, there was no constant rate period in drying of black pepper. All the drying process occurred in the falling rate period. In the falling rate period, the material surface was no longer saturated with water and drying rate was controlled by diffusion of moisture from the interior of solid to the surface (Diamante and Munro, 1993) [8]. Similar results have been presented for drying of red chillies (Mangaraj, 2001) [21], green peas (Thakur, 2008) [25].

In the graph of moisture content verses drying rate, at the beginning of drying process, when moisture content was high, drying rate was also very high and as moisture content approached to equilibrium moisture content, drying rate was very low. This is in agreement with the results of the study on sun drying of plums (Doymaz, 2004a) [9], mulberry (Doymaz, 2004b) [10] and figs (Doymaz, 2005b) [12].

Modeling of sun drying curves

Moisture ratio data of Panniyur-1 and Sreekara black pepper dried under sun were fitted to 8 thin layer models and the values of r^2, RMSE, MBE and χ^2 are summarized in Table 2. In all the cases, the values of r^2 were greater than 0.90 indicating a good fit (Erenturk *et al*., 2004) [14], but diffusion approximation model gave comparatively higher r^2 values in all the drying treatments (0.9899 and 0.9966) and also the RMSE (0.031 and 0.022), MBE (0.002 and 0.005) and χ^2 (0.001 and 0.001) values were lower for Panniyur-1 and Sreekara respectively. Hence, diffusion approximation model may be assumed to represent the thin layer drying behaviour of black pepper under sun. The predicted moisture ratios are in good agreement with the observed values and therefore it can be concluded that Diffusion approximation is relatively better than other 7 models (Fig. 2). Ebru and Yildiz (2003)[13] compared eleven thin layer drying models to study drying characteristics of red pepper and found that the drying process was best described by diffusion approximation model.

Effective moisture diffusivity

Effective moisture diffusivity was calculated using slopes derived from ln MR versus time (Fig. 3). The effective moisture diffusivity for drying black pepper was 4.13 x 10^{-07} m^2s^{-1} for Sreekara and 4.90 x 10^{-07} m^2s^{-1} for Panniyur-1. The estimated moisture diffusivity is comparable with the reported values of 1.5 x 10^{-9} m^2/s for raisin (Lomauro *et al.*, 1985), 2.64 x 10^{-9} to 5.71 x 10^{-9} m^2/s for green beans (Doymaz, 2005a) [11].

Table 1: Thin layer drying models

S. No.	Model name	Model	Reference
1.	Newton	MR = exp(-kt)	Ayensu, (1997) [3]
2.	Henderson and Pabis	MR = a exp(-kt)	Henderson and Pabis, (1961) [18]
3.	Page	MR = exp $(-kt^n)$	Lopez *et al*., (2000) [20]
4.	Modified Page	MR = exp$[-(kt^n)]$	Babalis *et al*., (2006) [4]
5.	Overhults	MR = exp$[-(kt)^n]$	Overhults *et al*., (1973) [23]
6.	Logarithmic	MR = a exp(-kt) + c	Doymaz, (2004a) [9]
7.	Diffusion approximation	MR = a exp(−kt) + (1 − a)exp(−kbt)	Togrul and Pehlivan, (2003) [27]
8.	Wang and Singh	MR = 1 + at + bt^2	Ertekin and Yaldiz, (2004) [15]

Table 2: Values of model constants and statistical parameters

Model	Variety	K	n	a	b	c	r^2	RMSE	MBE	χ^2
Diffusion approximation	P	0.193	-	-3.107	0.830	-	0.9899	0.031	0.002	0.001
	S	0.330	-	-0.525	0.393	-	0.9966	0.022	0.005	0.001
Wang and Singh	P	-	-	-0.070	0.001	-	0.9838	0.046	-0.003	0.003
	S	-	-	-0.068	0.001	-	0.9928	0.029	-0.001	0.001
Two Term Exponential	P	32.929	-	0.003	-	-	0.9793	0.042	-0.007	0.002
	S	12.057	-	0.008	-	-	0.9807	0.041	-0.010	0.002
Newton	P	0.1007	-	-	-	-	0.9796	0.042	-0.007	0.002
	S	0.093	-		-		0.9821	0.039	-0.006	0.002
Logrithmic	P	0.097	-	1.059	-	-0.029	0.9828	0.040	-0.002	0.002
	S	0.096	-	1.079	-	-0.016	0.9878	0.037	-0.005	0.002
Page	P	0.055	1.249	-	-	-	0.9895	0.031	0.003	0.001
	S	0.045	1.306	-	-	-	0.9959	0.025	0.009	0.001
Henderson and Pabis	P	0.104	-	1.039	-	-	0.9814	0.041	-0.010	0.002
	S	0.100	-	1.068	-	-	0.9875	0.037	-0.010	0.002
Overhults	P	0.098	1.249	-	-	-	0.9895	0.031	0.003	0.001
	S	0.093	1.306	-	-	-	0.9959	0.025	0.009	0.001

Modified Page	P	0.706	0.141			-	0.9796	0.042	0.009	0.002
	S	0.681	0.136	-	-	-	0.9821	0.039	-0.006	0.002

(P: Panniyur, S Sreekara)

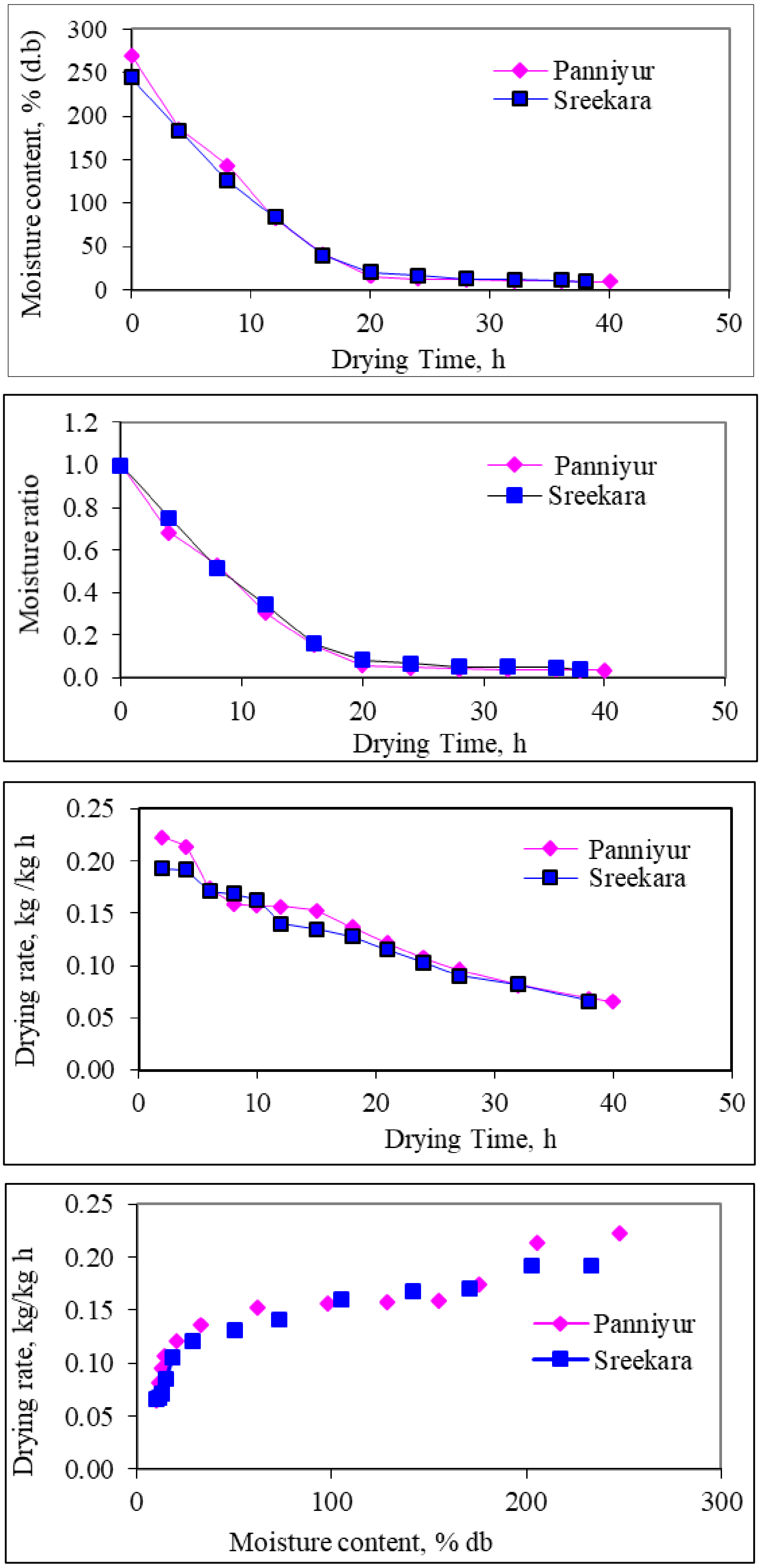
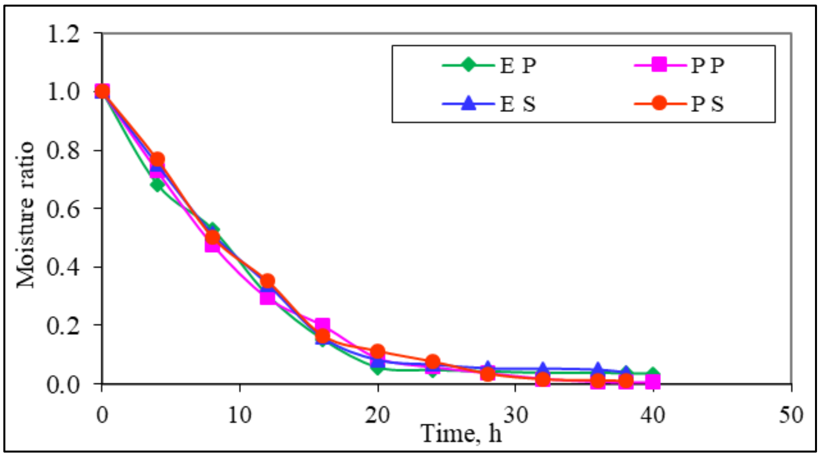


Fig 1: Sun drying characteristics of black pepper



(EP: Expected Panniyur-1; PP: Predicted Panniyur-1; ES: Expected Sreekara; PP: Predicted Sreekara)

Fig 2: Predicted and observed moisture ratio for drying of black pepper under sun

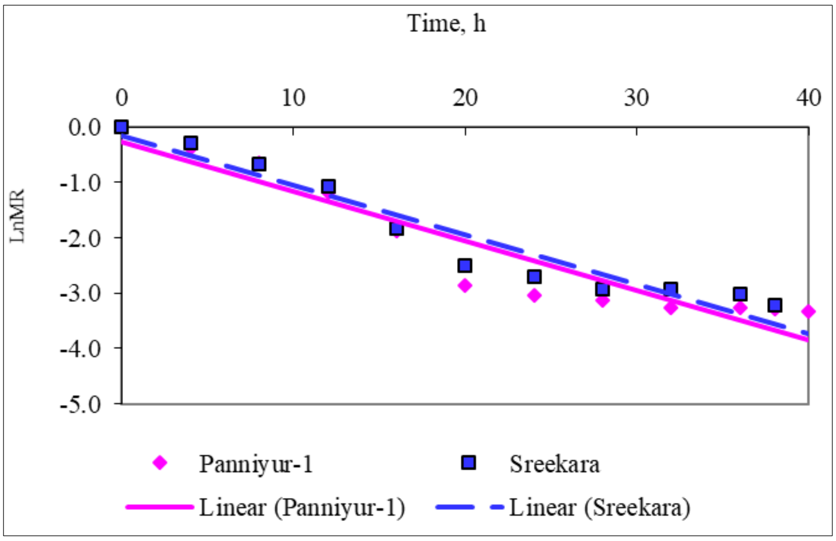


Fig 3: Effective moisture diffusivity for drying of black pepper

Conclusion

Sun drying characteristics of two varieties of black pepper *viz.* Sreekara and Panniyur-1 was studied. The drying data were fitted to eight different mathematical models. Among the models, the diffusion approximation model was found most suitable to explain the thin layer open sun drying behaviour of black pepper. The effective moisture diffusivity during drying of black pepper was 4.13 x 10^{-07} m^2s^{-1} for Sreekara and 4.90 x 10^{-07} m^2s^{-1} for Panniyur-1.

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References

1. Akpinar EK. Mathematical modelling of thin layer drying process under open sun of some aromatic plants. Journal of Food Engineering. 2006;77:864–870.
2. Akpinar EK, Bicer Y, Cetinkaya F. Modelling of thin layer drying of parsley leaves in a convective dryer and under open sun. Journal of Food Engineering. 2006;75:308-315.
3. Ayensu A. Dehydration of food crops using a solar dryer with convective heat flow. Solar Energy. 1997;59:121-126.
4. Babalis SJ, Elias P, Nikolas K, Vassilios GB. Evaluation of thin-layer drying models for describing drying kinetics of figs (*Ficus carica*). Journal of Food Engineering. 2006;75:205–214.
5. Beltagy AE, Gamea GR, Essa AHA. Solar drying characteristics of strawberry. Journal of Food Engineering. 2007;78:456–464.
6. Crank J. The Mathematics of Diffusion, 2nd Edn. Oxford University Press, London, U.K. 1975.
7. Diamante LM, Munro PA. Mathematical modelling of hot air drying of sweet potato slices. International Journal Food Science and Technology. 1991;26:99-109.
8. Diamante LM, Munro PA. Mathematical modelling of the thin layer solar drying of sweet potato slices. Solar Energy. 1993;51:271–276.
9. Doymaz I. Effect of dipping treatment on air drying of plums. Journal of Food Engineering. 2004a;64:465–470.
10. Doymaz I. Pretreatment effect on sun drying of mulberry fruits (*Morus alba* L.), Journal of Food Engineering.

2004b;65:205-209.
11. Doymaz I. Drying behaviour of green beans. Journal of Food Engineering. 2005a;69:161-165.
12. Doymaz I. Sun drying of figs: An experimental study. Journal of Food Engineering. 2005b;71:403–407.
13. Ebru KSB, Yildiz C. Thin layer drying of red pepper. Journal of Food Engineering. 2003;59:99-104.
14. Erenturk S, Gulaboglu MS, Gultekin S. The thin layer drying characteristics of rosehip. Biosystems Engineering. 2004;89:159-156.
15. Ertekin C, Yaldız O. Drying of eggplant and selection of a suitable thin layer-drying model. Journal of Food Engineering. 2004;63:349–359.
16. Geankoplis CJ. Drying of Process Materials. In: Transport processes and separation process principles, 4th Edn. Prentice-Hall of India private limited, 2003. p. 559-611.
17. Hayaloglu AA, Karabulut I, Alpaslan M, Kelbaliyev G. Mathematical modeling of drying characteristics of strained yoghurt in a convective type tray-dryer. Journal of Food Engineering. 2007;78:109-117.
18. Henderson SM, Pabis S. Grain drying theory I: Temperature effect on drying coefficient. Journal of Agricultural Research and Engineering. 1961;6:169–174.
19. Lomauro CJ, Bakshi AS, Labuza TP. Moisture transfer properties of dry and semimoist foods. Journal of Food Science. 1985;50:397–400.
20. Lopez A, Iguaz A, Esnoz A, Virseda P. Thin-layer drying behaviour of vegetable wastes from wholesale market. Drying Technology. 2000;18:995–1006.
21. Mangaraj S, Singh A, Samuel DVK, Singhal OP. Comparative performance evaluation of different drying methods for chillies. Journal of Food Science and Technology. 2001;38:296–299.
22. Midilli A, Kucuk H, Yapar Z. A new model for single layer drying. Drying Technology. 2002;20:1503–1513.
23. Overhults DG, White HE, Hamilton HE, Ross IJ. Drying soybeans with heated air. Transaction of ASAE. 1973;16:112-113.
24. Pruthi JS. Major Spices of India: Crop Management and Post-Harvest Technology. ICAR, New Delhi, 1993. p. 44-105.
25. Thakur AK. Studies on drying characteristics and physical evaluation of green peas. Journal of Food Science and Technology. 2008;45:117-122.
26. Togrul IT, Pehlivan D. Mathematical modelling of solar drying of apricots in thin layers. Journal of Food Engineering. 2002;55:209–216.
27. Togrul IT, Pehlivan D. Modelling of drying kinetics of single apricot. Journal of Food Engineering. 2003;58:23–32.
28. Togrul IT, Pehlivan D. Modelling of thin layer drying kinetics of some fruits under open-air sun drying process. Journal of Food Engineering. 2004;65:413–425.
29. Vagenas GK, Karathanos VT. Prediction of the moisture diffusivity in gelatinised starch materials. Journal of Food Engineering. 1993;18:159–179.
30. Yaldız O, Ertekin C, Uzun HI. Mathematical modeling of thin layer solar drying of Sultana grapes. Energy-An International Journal. 2000;26:457-465.