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Mathematical modeling of convective thin layer drying of basil leaves

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Basil leaves are well known for the medicinal values and grown widely in India. To investigate the effect of different drying conditions on kinetics of basil leaves, the laboratory models of tunnel and tray dryers were employed and air temperatures of 55, 60 and 65°C were considered for the drying. Drying of basil leaves prominently occurred in falling rate period and it was found that basil leaves dried faster in tray dryer. Six thin layer-drying models were fitted to the experimental moisture ratio data. Among the mathematical models investigated, the logarithmic model satisfactorily described the drying behaviour of basil leaves with highest r^2 values. The effective moisture diffusivity (D_{eff}) of basil leaves increased with the increase in drying air temperature. The D_{eff} values were higher for tray dryer than those dried in the tunnel dryer. Effective moisture diffusivity of basil leaves ranged from 2.65×10^{-10} to 5.69×10^{-10} m^2/s. An Arrhenius relation was employed to ascertain activation energy for the samples dried in both types of dryers and activation energy for basil leaves drying ranged from 33.21 to 9.03 kJ/mol.

Key words: Activation energy, diffusivity, drying; models, basil leaves, tray dryer, tunnel dryer.

INTRODUCTION

Basil (*Ocimum sanctum*) which is popularly known as *Tulsi* is a widely grown, sacred plant of India. It belongs to the Labiateae family and called Holy Basil in English. Dark or *Shyama tulsi* and light or *Rama tulsi* are the two main varieties of basil and the former one possesses higher medicinal values. *Tulsi* is a branched, fragrant and erect herb having hair all over. It attains a height of about 75 to 90 cm when mature. Its leaves are nearly round and up to 5 cm long with the margin being entire or toothed. Basil leaves are aromatic because of the presence of a kind of scented oil.

Apart from basil leaves' religious significance, it is a source of many medicinal characteristics and usually used in "Ayurvedic" treatment to cure a number of diseases. Marked by its strong aroma and a stringent taste, *Tulsi* is a kind of "the elixir of life" as it promotes longevity. The plant extracts can be used to prevent and cure many illnesses and common ailments like common cold, headaches, stomach disorders, inflammation, heart disease, various forms of poisoning and malaria. *Tulsi* leaves contain a bright yellow volatile oil, which is useful against insects and bacteria. The principal constituents of the oil are eugenol, eugenol methyl ether and carvacrol. The oil is reported to possess anti-bacterial properties and acts as an insecticide. It has marked insecticidal activity against mosquitoes. The juice of leaves, and or a concoction, called jushanda, a kind of tea, gives relief in common cold, fever, bronchitis, cough, digestive complaints, etc. When applied locally, it helps in eradicating ringworms and other skin diseases. *Tulsi* oil is also used as eardrops in case of pain. The seeds are used in curing urinary problems. Aphrodisiac virtue has been attributed to it and powdered *Tulsi* root with clarified butter (ghee) is prescribed for the same in "Ayurvedic "treatment.

Drying is one of the oldest methods of food preservation and it represents a very important aspect of food processing. The main aim of drying products is to allow longer periods of storage, minimize packaging

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requirements and reduce shipping weights (Okos et al., 1992), the drying process should be undertaken in closed equipment to improve the quality of the final product (Ertekin and Yaldiz, 2004).

Thin layer equations describe the drying phenomena in a united way, regardless of the controlling mechanism. They have been used to estimate drying time of several products and to generalize 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; Togrul and Pehliavan, 2002). Thin layer drying equations do not require evaluation of many models parameters as common in more complex representations (Madamba et al., 1996).

Akpinar (2006) studied the sun drying behaviour of aromatic plants as parsley, mint and basil and the drying data was fitted to twelve different mathematical models. The Modified page (I) model for mint and basil leaves were found to best explain thin layer open sun drying behaviour of the aromatic plants. Özcan et al. (2005) reported that basil can be oven dried at 50°C to 17.31% moisture content after 15 h and can be sun dried to 23.79% moisture content after 28 h. In an another study, dried basil leaves were evaluated for retention of some volatile compounds using both conventional hot air (50, 60 and 70°C) and low-pressure superheated steam (LPSS) dryers. The LPSS drying proved to be better in terms of the aroma compounds content (Barbieri et al., 2004). Soysal (2004) dried parsley leaves (*Petroslinum crispum* Mill.) in a domestic microwave oven and found semi-empirical page's equation described the drying kinetics of dried leaf. Yousif et al. (1999) used conventional hot air or the vacuum-microwave dryers to study the effect of the basil leaves drying method on the relative abundance of major flavor volatiles, rehydration rate, color, and structural integrity of the plant. Vacuum-microwave dehydrated basil yielded approximately 2.5 times the linalool and 1.5 times the methylchavicol of the air-dried samples. Rocha et al. (1993) studied the effects of steam blanching, surfactant pretreatment and drying conditions on the drying rate and on the chlorophyll and colour retention of air-dried basil and found that steam blanching and surfactant pretreatments increased drying rates by a factor of 10 and 14, respectively. Both pretreatments resulted in a better retention of the overall green colour of the basil leaves. Kadam et al. (2011) investigated the drying kinetics of basil leaves and reported that two term model best described the drying kinetics.

Earlier studies indicated the significant effect of type of dryer on drying kinetics of basil leaves as well as theirs characteristic properties, so the presented study was conducted to investigate the influence of drying methods (tray and tunnel drying) with different drying air temperature (55, 60 and 65°C) on drying kinetics of basil leaves, to evaluate a suitable thin layer drying model, and to calculate the effective moisture diffusivities and activation energy.

THEORETICAL CONSIDERATIONS

Mathematical formulation

The moisture contents of basil leaves were expressed in dimensionless form as moisture ratios MR with the following equation (Midilli et al., 1999; Midilli, 2001; Erenturk et al., 2004).

$$MR = \frac{M - M_e}{M_0 - M_e} \tag{1}$$

Where: M is the mean basil moisture content; M_o is the initial value; and M_e is the equilibrium moisture content. The M_e values were neglected because the values were very small as compared to those of M_o and M and the moisture ratio was simplified as per the following relationship (Pala et al., 1996; Doymaz 2004a; Goyal et al., 2007):

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

The drying data was analyzed for six thin layer drying models to select the best model to describe the drying curve equation of basil leaves. Software “STATISTICA” was employed for non-linear regression analysis of drying data.

The coefficient of determination, r^2 was one of the primary and main criteria for selecting the best equation to account for variation in the drying curves of dried samples (Ozdemir and Devres, 1999; Yaldiz et al., 2001; Erenturk et al., 2004).

In addition to coefficient of determination, the goodness of fit was determined by various statistical parameters such as reduced chi-square (χ^2), mean bias error (MBE), and root mean square error (RMSE). The best fit was decided for highest value of r^2 and minimum value of χ^2, MBE and RMSE (Pangavhane et al., 1999; Sarsavadia et al., 1999; Togrul and Pehlivan, 2002; Demir et al., 2004; Erenturk et al., 2004; Goyal et al., 2007). The following mathematical relationship was utilized to calculate the mentioned statistical parameters:

$$\chi^2 = \frac{\sum_{i=1}^{N} (MR_{\exp.i} - MR_{pre.i})^2}{N - z} \tag{3}$$

$$MBE = \frac{1}{N}\sum_{i=1}^{N} (MR_{pre.i} - MR_{\exp.i}) \tag{4}$$

$$RMSE = \left[\frac{1}{N} \sum_{i=1}^{N} (MR_{pre,i} - MR_{\exp,i})^2 \right]^{1/2} \quad (5)$$

Effective moisture diffusivity

Fick's diffusion equation, for particles with slab geometry, was used for calculation of effective moisture diffusivity. The basil leaves were considered as slab geometry (Doymaz, 2006) for the purpose. The following equation was used for the purpose (Crank, 1975):

$$MR = \frac{8}{\pi^2} \exp\left(\frac{-\pi^2 D_{eff} t}{4 L^2} \right) \quad (6)$$

Equation (6) can be rewritten as:

$$\ln MR = D_{eff} k_0 + \ln \frac{8}{\pi^2} \quad (7)$$

Where, the slope (k_o) is calculated by plotting ln(MR) versus time according to Equation (7) to determine the effective diffusivity for different temperatures.

$$k_o = -\left(\frac{\pi^2 D_{eff}}{4 L^2} \right) \quad (8)$$

Activation energy

The effective diffusivity can be related with temperature by Arrhenius equation (Simal et al., 1996):

$$D_{eff} = D_0 \exp\left[-\frac{E_a}{R(T + 273.15)} \right] \quad (9)$$

where, D_0 is the constant in Arrhenius equation in m^2s^{-1}, E_a is the activation energy in kJ. mol^{-1}, T is the temperature in °C and R is the universal gas constant in kJ. $mol^{-1}.K^{-1}$. Equation (9) can be rearranged in the form of :

$$\ln(D_{eff}) = \ln(D_0) - \frac{E_a}{R(T + 273.15)} \quad (10)$$

The activation energy can be calculated by plotting a curve between $\ln(D_{eff})$ versus 1/(T+273.15).

MATERIALS AND METHODS

Experimental material

Basil or *Tulsi* leaves (*Ocimum sanctum*) were harvested from CIPHET, Ludhiana farm and properly washed in tap water. Excess surface water from washed basil leaves was removed using blotting paper with slight pressing. Clean leaves were weighed using electronics balance (Citizen Instruments, India with least count of 0.01 mg) and put in trays for drying in tray and tunnel dryers. To establish the influence of air temperature on drying curve, experiments were conducted at 55, 60 and 65°C. The initial moisture content of basil leave was 932.87% d.b. and it was determined by the AOAC method no. 934.06 (AOAC, 2000). Basil leave average thickness was 0.33 ± 0.08 mm) and were dried on the same day.

Drying equipment and procedure

The drying experiments on basil leaves were performed in a laboratory model cross flow tunnel dryer (NSW-600, Narang Scientific Works, New Delhi) and a tray dryer (Mac Scientific Works, New Delhi). Tunnel dryer's overall dimensions were 3.06 x 1.10 x 2.15 m and it consisted of a tunnel, electrical heater, fan and a temperature controller (30 to 110°C, db). The speed of the tunnel was fixed at 0.004 m/s. Tray dryer had 10 trays in two columns with an electrical heater, fan and a temperature controller range from 30 to 110°C (db).

Drying experiments were conducted at 55, 60 and 65°C (± 1°C) in both the drying methods. The dryer was allowed to run for 30 min to reach the set drying air temperature conditions. Basil leaves sample size of 100 ± 0.5 g for all runs were uniformly spread in rectangular trays and kept in the tunnel and tray dryer for drying. Moisture loss was recorded at 30 min interval by a digital balance with lease count of 0.01 mg (Citizen Instruments, India). The drying was continued till there is no large variation in the moisture loss. Experiments were conducted in triplicate.

RESULTS AND DISCUSSION

Drying characteristics

Figure 1 present relation between moisture ratio and drying time for all three drying temperature in both type of dryers. Constant rate-drying period was not detected in drying curves and the curves typically demonstrated smooth diffusion controlled drying behaviour under all run conditions. Drying rate increased with the increase of air-drying temperature in both drying methods. Highest drying rates were observed for the samples dried at 65°C of the drying air for both dryers. Similar observations have been reported for the drying of red chillies (Chandy et al., 1992), onion slices (Rapusas and Driscoll, 1995) and apricots (Doymaz, 2004a) and mint leaves (kadam et al., 2011). The drying of basil leaves occurred primarily in falling rate period and that showed that internal mass transfer occurred by diffusion. Drying time differed with respect to the type of dryer and it has been presented in Table 1 for different drying conditions. The final moisture content of basil leaves ranged from 8.83 to 15.13% (d.b.) depending on the drying air temperature and type of

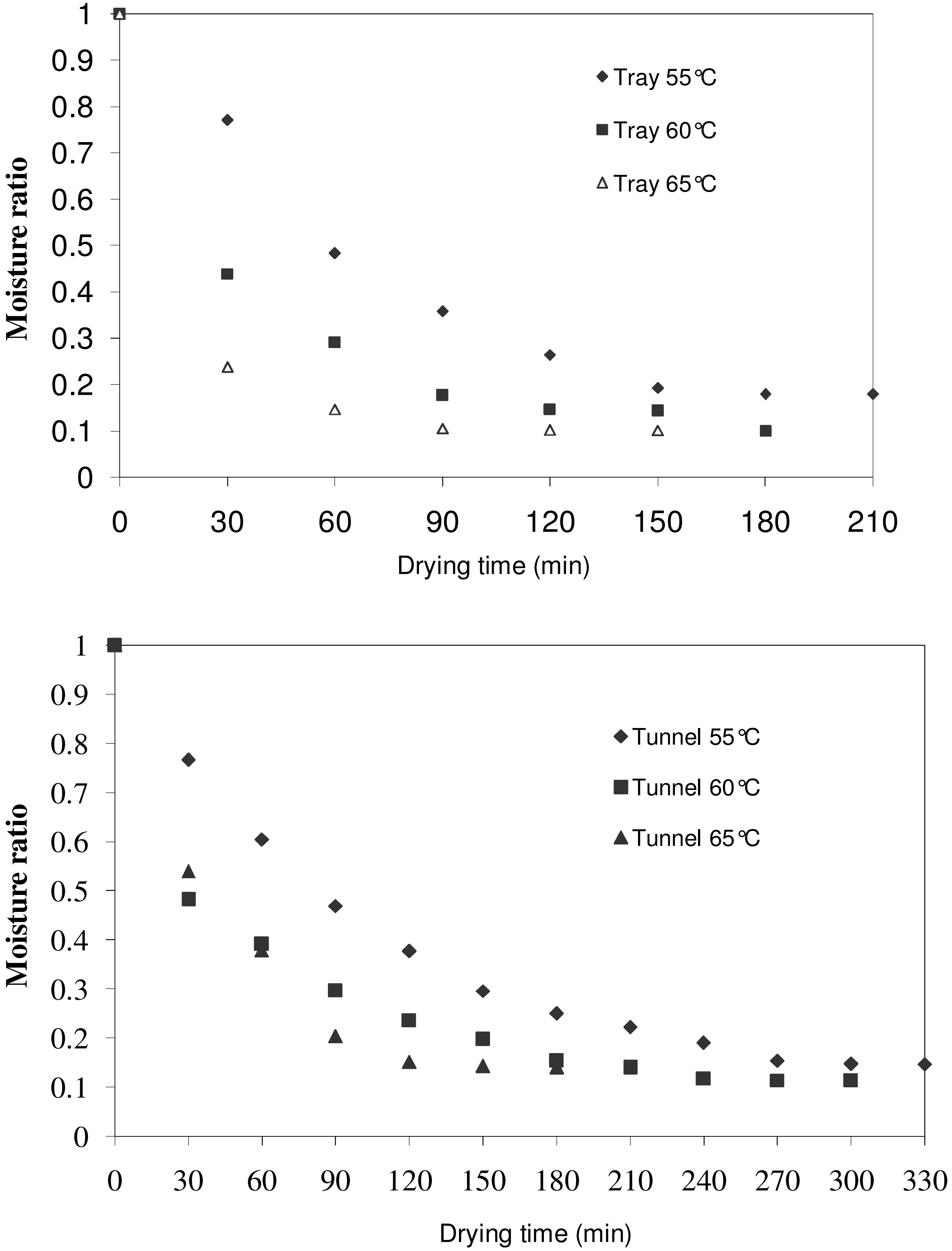


Figure 1. Effect of drying temperature on basil leaves drying time of tray and tunnel dryer.

Table 1. Treatment as drying methods and temperature during basil leaves drying with drying time.

Treatment	Drying method	Drying air temperature, °C	Basil leaves drying time, min
T1	Tray drying	65	150
T2	Tray drying	60	180
T3	Tray drying	55	210
T4	Tunnel drying	65	210
T5	Tunnel drying	60	300
T6	Tunnel drying	55	330

dryer. The samples dried in tray dryer took lesser time than those dried in the tunnel dryer. It is evident that the drying air temperature has an important effect on drying. When the temperature was increased, the drying time reduced. The results are similar with the earlier observations on drying of garlic slices (Madamba et al., 1996) and onion slices (Sarsavadia et al., 1999). The similar findings were also reported by Kadam et al. (2011) for mint leaves.

Mathematical models for fitting drying curves

The moisture content data at the different drying air temperature and drying methods were converted to moisture ratio and the data was analyzed for the mentioned thin layer drying models. The coefficient of correlation and results of statistical analyses are listed in Table 2a and models' constants are presented in Table 2b. For all mentioned thin layer drying models, r^2 values were greater than 0.90 except Page model at T3 and T5 and Wang and Singh Model at T2 and T5. The analysis indicated that logarithmic model had highest values of r^2 with lowest values of χ^2, MBE and RMSE. Thus, the logarithmic model represented the thin layer drying behaviour of basil leaves in both tray and tunnel dryers. Similar findings were reported for hot air drying of apricots (Togrul and Pehlivan, 2002; Doymaz, 2004a), rosehip (Erenturk et al., 2004) and plum (Goyal et al., 2007). Plots of experimental and predicted moisture ratio values by logarithmic model are shown in Figure 2. It showed that logarithmic model fitted well within temperature range of 55 to 65°C under both tray and tunnel drying methods of basil leaves.

Effective moisture diffusivity

Values of D_{eff} with coefficient of correlation, r^2, are given in Table 3. Effective moisture diffusivity of basil leaves ranged from 2.65×10^{-10} to 5.69×10^{-10} m^2/s. These values are within the general range 10^{-9} to 10^{-11} m^2/s for drying of food materials (Maskan et al., 2002). The moisture diffusivity increased as drying air temperature was increased. Kadam et al. (2011) also discussed that moisture diffusivity increased with the increase in drying air temperature for mint leaves drying. Effective moisture diffusivity of basil leaves was higher in tray dyer as compare to that in tunnel dryer irrespective of drying air temperature. The maximum r^2 value was 0.968 in tunnel dryer at 55°C and it was minimum 0.8451 in tunnel dryer at 65°C.

Activation energy

Activation energy is the minimum energy required to initiate moisture diffusion from a product. The curves between $\ln(D_{eff})$ and $1/(T+273.15)$ plotted to calculate activation energy for the drying methods were shown in Figure 3. The plots were found to be essentially the straight lines in the temperature range investigated indicating Arrhenius dependence. From the slop of the straight lines described by the Arrhenius equation, the activation energy was found to be 33.21 and 39.03 kJ/mol respectively for tray and tunnel drying of basil leaves. The comparison with literature values for various leafy and non-leafy vegetables is shown in Table 4. It is lower than the activation energy of green pea (Simal et al., 1996), black tea (Panchariya et al., 2002), mint (Doymaz, 2006), slightly higher than carrot (Doymaz, 2004b), and close to red pepper (Kaymak-Ertekin, 2002).

Conclusions

Drying of basil leaves study was carried to determine the effect of drying methods (Tray and Tunnel dryers) and drying air temperature. The results show that the increase in drying air temperature decreased the drying time in both the drying methods. About 210 min are required to dry the basil at air temperature of 55°C and 150 min at 65°C in tray dryer. Logarithmic thin layer drying equation represented the thin layer drying behaviour of basil leaves. Effective moisture diffusivity of basil leaves ranged from 2.65×10^{-10} to 5.69×10^{-10} m^2/s. Effective moisture diffusivity of basil leaves was higher in tray dyer as compared to that of tunnel dryers irrespective of drying air temperature. Activation energy was 33.21 and 39.03 kJ/mol for drying of basil leaves for

Table 2a. Statistical quality analyses of fitted mathematical models to thin layer drying data of basil leaves.

Name of the model	Model equationtreatment	r^2	χ^2	MBE	RMSE
Newton	MR = Exp (-kt)				
	T1	0.95684	0.00472	0.01377	0.02562
	T2	0.93784	0.00685	0.04938	0.02896
	T3	0.98295	0.00160	0.00522	0.01324
	T4	0.95628	0.00406	0.01508	0.02106
	T5	0.89046	0.00762	0.01885	0.02509
	T6	0.98528	0.00112	0.00305	0.00925
Page	$MR = Exp\ (-kt^n)$				
	T1	0.99863	0.00030	0.00067	0.00645
	T2	0.99898	0.00022	0.00049	0.00524
	T3	0.75295	0.04754	0.00000	0.06676
	T4	0.98690	0.00142	0.00274	0.01153
	T5	0.99787	0.00016	-0.00011	0.00350
	T6	0.49281	0.04241	0.00000	0.05427
Henderson and Pabis	MR = a Exp (-kt)				
	T1	0.97965	0.00551	0.01810	0.02475
	T2	0.96856	0.00818	0.05072	0.02890
	T3	0.99144	0.00187	0.00513	0.01324
	T4	0.95942	0.00439	0.01825	0.02029
	T5	0.91284	0.00674	0.02056	0.02238
	T6	0.98777	0.00102	0.00605	0.00843
Logarithmic	MR = a Exp (-kt) + c				
	T1	0.99700	0.00055	0.00000	0.00676
	T2	0.99925	0.00012	0.00000	0.00318
	T3	0.99054	0.00125	0.00000	0.00987
	T4	0.99480	0.00067	0.00000	0.00726
	T5	0.97789	0.00192	0.00000	0.01127
	T6	0.99948	0.00005	0.00000	0.00173
Wang and Singh	$MR = 1 + at + bt^2$				
	T1	0.95012	0.00682	-0.01280	0.02754
	T2	0.77852	0.02929	-0.03048	0.05467
	T3	0.99439	0.00062	0.00016	0.00760
	T4	0.95249	0.00514	-0.01333	0.02196
	T5	0.81395	0.01438	-0.02774	0.03270
	T6	0.98302	0.00142	-0.00783	0.00993
Two term exponential	MR = a Exp(-kt) + (1-a) Exp(-kat)				
	T1	0.98052	0.00266	0.00709	0.01721
	T2	0.95126	0.00645	0.03717	0.02565
	T3	0.98291	0.00188	0.00498	0.01326
	T4	0.97707	0.00248	0.00795	0.01525
	T5	0.94210	0.00447	0.01071	0.01824
	T6	0.99685	0.00026	0.00162	0.00427

Table 2b. Statistical quality analyses of fitted mathematical models to thin layer drying data of basil leaves.

Name of the model	MR model equation	Treatment	Constants					Standard error				
			k	a	b	C	n	k	a	b	C	n
Newton	MR = Exp (-kt)											
		T1	0.02067					0.002285				
		T2	0.03921					0.007359				
		T3	0.01059					0.000517				
		T4	0.01591					0.001420				
		T5	0.01309					0.001441				
		T6	0.00760					0.000256				
Page	MR = Exp ($-kt^n$)											
		T1	0.11328				0.587421	0.02310				0.04784
		T2	0.55039				0.293720	0.09571				0.04017
		T3	1.05911				6.26E-07	1.71204				0.34699
		T4	0.06519				0.675245	0.022015				0.07507
		T5	0.11748				0.522901	0.010583				0.018821
		T6	1.11012				0.000001	1.338601				0.239886
Henderson and Pabis	MR = a Exp (-kt)											
		T1	0.01978	0.96091				0.00277	0.07095			
		T2	0.03866	0.98621				0.00835	0.09002			
		T3	0.01059	1.00073				0.00070	0.03742			
		T4	0.01513	0.956840				0.00171	0.06087			
		T5	0.01118	0.882530				0.00151	0.07083			
		T6	0.00728	0.963514				0.00032	0.02492			
Logarithmic	MR = a Exp (-kt) + c											
		T1	0.032775	0.858917		0.137637		0.002828	0.027782		0.017481	
		T2	0.061830	0.895261		0.104275		0.002937	0.012322		0.005400	
		T3	0.013732	0.924988		0.098661		0.001856	0.045555		0.042384	
		T4	0.023385	0.878141		0.120333		0.001908	0.028452		0.016908	
		T5	0.021522	0.833966		0.135791		0.002664	0.044704		0.020265	
		T6	0.009986	0.896104		0.104849		0.000215	0.006974		0.005864	
Wang and Singh	MR = 1 + at + bt^2											
		T1		-0.016237	7.22E-05				0.001518	1.20E-05		
		T2		-0.017207	7.13E-05				0.002429	1.62E-05		
		T3		-0.009477	2.68E-05				0.000282	0		
		T4		-0.012203	4.01E-05				0.000817	0		
		T5		-0.008932	2.10E-05				0.000819	0		
		T6		-0.006492	1.22E-05				0.000224	0		

Table 2b. Contd.

Two term exponential	MR = a Exp(-kt) + (1-a) Exp(-kat)					
	T1	0.061758	0.257289		0.189915	0.663860
	T2	0.0847726	0.331193		0.689085	2.282965
	T3	1.4300463	0.007335		13.75951	0.074174
	T4	0.043241	0.277954		0.069026	0.375958
	T5	0.043677	0.233472		0.099019	0.446961
	T6	0.0184268	0.304922		0.004639	0.066007

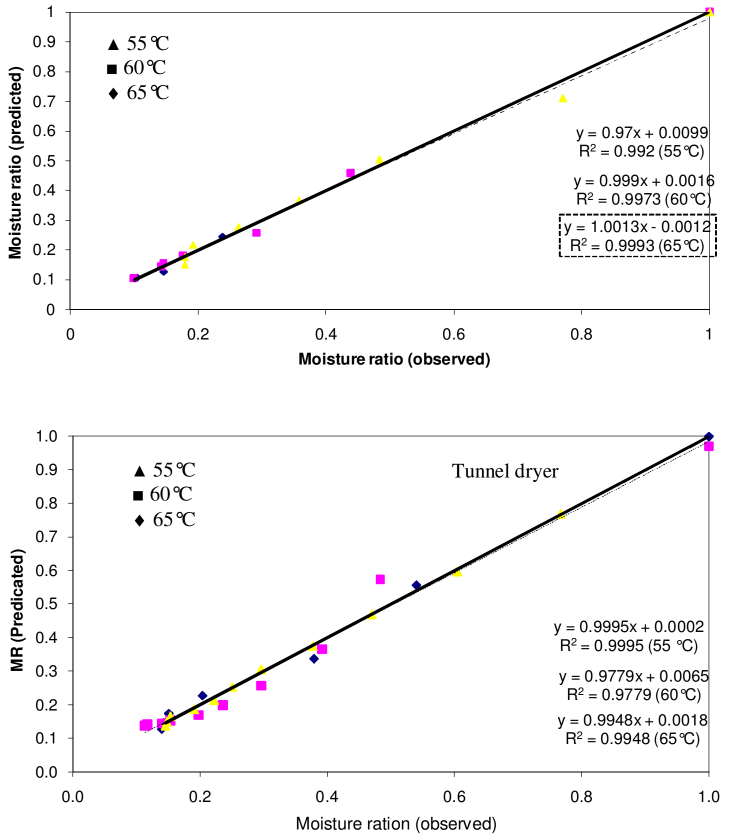
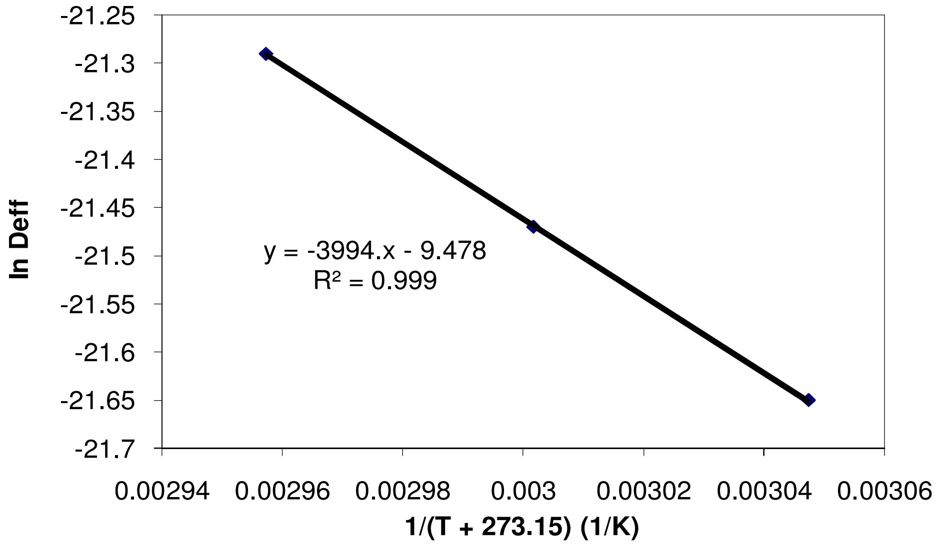


Figure 2. Relationship between observed and predicted moisture ratio using logarithmic model during tunnel drying of basil leaves.

Table 3. Moisture diffusivity and its linear equation for basil leaves at different treatments.

Drying method	Drying air temperature, °C	Linear equation	k_0	D_{eff}	r^2
Tray dryer	55	y = -0.0089x - 0.1217	-0.0089	3.93E-10	0.943
	60	y = -0.0107x - 0.819	-0.0107	4.72E-10	0.671
	65	y = -0.0129x - 0.3102	-0.0129	5.69E-10	0.898
Tunnel drying	55	y = -0.006x - 0.168	-0.006	2.65E-10	0.968
	60	y = -0.0067x - 0.4702	-0.0067	2.96E-10	0.908
	65	y = -0.0094x - 0.3797	-0.0094	4.15E-10	0.845

Tray dryer



Tunnel dryer

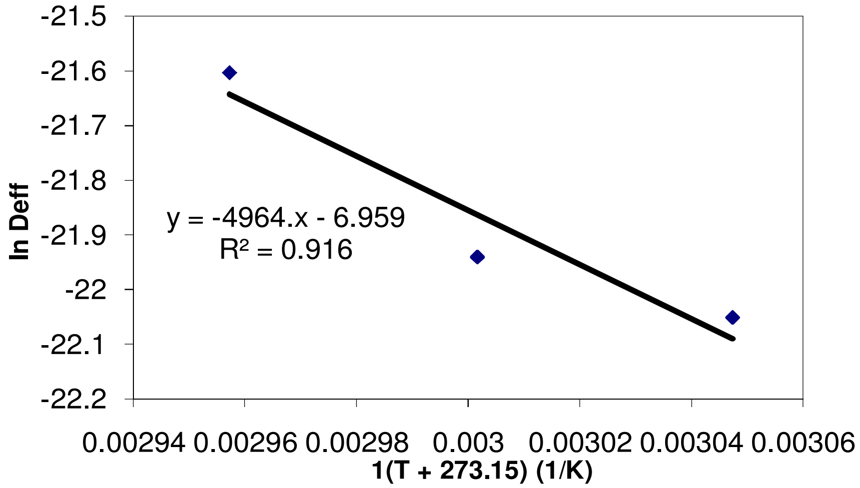


Figure 3. Effect of air temperature on the effective diffusivity of basil leaves in tray and tunnel drying.

Table 4. Comparison of activation energy values with literature values.

Material	Activation energy (E_a) (kJ/mol)	References
Basil (tray dryer)	33.21	Present study
Basil (tunnel dryer)	39.03	Present study
Mint	62.56	Doymaz (2006)
Carrot	82.93	Doymaz (2004b)
Red pepper	42.80	Kaymak-Ertekin (2002)
Green peas	24.70	Simal et al. (1996)
Black tea	406.02	Panchariya et al. (2002)

the samples dried in tray and tunnel dryers.

REFERENCES

Akpinar E (2006). Mathematical modelling of thin layer drying process under open sun of some aromatic plants. J. Food Eng., 77(4): 864-870.

AOAC (2000). In: Official Methods of Analysis of the Association of Official Analytical Chemists (17th ed.) (ed.W. Horwitz). AOAC International, Maryland, USA.

Barbieri S, Elustondo M, Urbicain M (2004). Retention of aroma compounds in basil dried with low pressure superheated steam. J. Food Eng., 65(1): 109-115.

Chandy E, Ilyas SM, Samuel DVK, Singh A (1992). Effect of some physical treatments on drying characteristics of red chillies. In: Proceedings of the International Agricultural Engineering Conference, Bangkok, Thailand.

Crank J (1975). Mathematics of diffusion. Clarendon Press, Oxford, UK.

Demir V, Gunhan T, Yagcioglu AK, Degirmencioglu A (2004). Mathematical modelling and the determination of some quality parameters of air-dried bay leaves. Biosys. Eng., 88(3): 325-335.

Doymaz I (2004a). Effect of pre-treatments using potassium metabisulphite and alkaline ethyl oleate on the drying kinetics of apricots. Biosys. Eng., 89(3): 281-287.

Doymaz I (2004b). Convective air drying characteristics of thin layer carrots. J. Food Eng., 61: 359-364.

Doymaz I (2006). Thin layer drying behaviour of mint leaves. J. Food Eng., 74: 370-375.

Erenturk S, Gulaboglu MS, Gultekin S (2004). The thin layer drying characteristics of rosehip. Biosys. Eng., 89(2): 159-166.

Ertekin C, Yaldiz O (2004). Drying of eggplant and selection of a suitable thin layer drying models. J. Food Eng., 63: 349-359.

Goyal RK, Kingsly ARP, Manikanthan MR, Ilyas SM (2007). Mathematical modeling of thin layer drying kinetics of plum in a tunnel dryer. J. Food Eng., 79: 176-180.

Henderson SM, Pabis S (1961). Grain drying theory I. Temperature effect on drying coefficient. J. Agric. Eng. Res., 6(3): 169-174.

Kadam DM, Goyal RK, Singh KK, Gupta MK (2011). Thin layer convective drying of mint leaves. J. Med. Plant Res., 5(2): 164-170.

Kaymak EF (2002). Drying and rehydration kinetics of green and red pepper. J. Food Sci., 67: 168-175.

Madamba PS, Driscoll RH, Buckle KA (1996). The thin layer drying characteristic of garlic slices. J. Food Eng., 29: 75-97.

Maskan A, Kaya S, Maskan M (2002). Hot air and sun drying of grape leather (pestil). J. Food Eng., 54: 81-88.

Midilli A (2001). Determination of pistachio drying behaviour and conditions in solar drying systems. Int. J. Energy Res., 25: 715-725.

Midilli A, Kucuk H, Yapar Z (2002). A new model for single layer drying. Drying Technol., 20(7): 1503-1513.

Midilli A, Olgum H, Ayhan T (1999). Experimental studies on mushroom and pollen drying. Int. J. Energy Res., 23: 1143-1152.

Okos MR, Narsimhan G, Singh RK, Weitnauer AC (1992). Food Dehydration. In: Heldman DR, Lund DB (Eds). Handbook of food engineering, New York; Marcel Dekker.

Overhults DD, White GM, Hamilton ME, Ross IJ (1973). Drying soybeans with heated air. Trans. ASAE, 16: 195-200.

Özcan M, Arslan D, Ünver A (2005). Effect of drying methods on the mineral content of basil (Ocimum basilicum L.). J. Food Eng., 69(3): 375-379.

Ozdemir M, Devres YO (1999). The thin layer drying characteristic of hazelnuts during roasting. J. Food Eng., 42: 225-233.

Pala M, Mahmutoglu T, Saygi B (1996). Effects of pretreatments on the quality of open-air and solar dried products. Nahrung Food, 40: 137-141.

Panchariya PC, Popovic D, Sharma AL (2002). Thin layer modeling of black tea drying process. J. Food Eng., 52: 349-357.

Pangavhane DR, Sawhney RL, Sarsavadia PN (1999). Effect of various dipping pre-treatment on drying kinetics of Thompson seedless grapes. J. Food Eng., 39: 211-216.

Rapusas RS, Driscoll RH (1995). The thin layer drying characteristics of white onion slices. Drying Technol., 13(8 and 9): 1905-1931.

Rocha T, Lebert A, Marty AC (1993). Effect of Pretreatments and Drying Conditions on Drying Rate and Colour Retention of Basil (*Ocimum basilicum*). LWT, 26(5): 456-463.

Sarsavadia PN, Sawhney RL, Pangavhane DR, Singh SP (1999). Drying behaviour of brined onion slices. J. Food Eng., 40: 219-226.

Simal S, Mulet A, Tarrazo J, Rosello C (1996). Drying models for green peas. Food Chem., 55: 121-128.

Soysal Y (2004). Microwave Drying Characteristics of Parsley. Biosys. Eng., 89(2): 167-173.

Togrul IT, Pehlivan D (2002). Mathematical modelling of solar drying of apricots in thin layers. J. Food Eng., 55: 209-216.

Wang CY, Singh RP (1978). Use of variable equilibrium moisture content in modelling rice drying. ASAE Paper No. 78-6505, ASAE, St. Joseph, MI.

Yaldiz O, Ertekin C (2001). Thin layer solar drying of some vegetables. Drying Technol., 19: 583-596.

Yaldiz O, Ertekin C, Uzun HI (2001). Mathematical modelling of thin layer solar drying of sultana grapes. Energy. Int. J. 26: 457-465.

Yousif AN, Scaman CH, Durance TD, Girard B (1999). Flavor volatiles and physical properties of vacuum-microwave- and air-dried sweet basil (*Ocimum basilicum* L.). J. Agric. Food Chem., 47(11): 4777-4781.

Zhang Q, Litchfield JB (1991). An optimization of intermittent corn drying in a laboratory scale thin layer dryer. Drying Technol., 9: 383-395.