

Drying characteristics and prediction of best fitted drying model for coriander leaves

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ARTICLE INFO	ABSTRACT
<p>Received : 30 June 2021 Revised : 20 August 2021 Accepted : 30 August 2021</p> <p>Available online: 9 December 2021</p> <p>Key Words: Coriander Solar greenhouse dryer Drying rate Moisture Drying model</p>	<p>Drying experiments were conducted on coriander leaves as affected by drying methods (solar greenhouse drying and open sun drying), pretreatments (dipping in a solution of magnesium chloride + sodium bicarbonate + potassium metabisulphite, boiled water blanching containing sodium metabisulphite, and untreated), and loading densities (2.0, 2.5 and 3.0 kg/m²). Validity of three commonly used drying models were examined to predict the most suitable drying model for coriander leaves. The increased drying temperature under solar greenhouse dryer (42°C) increases the amount of moisture removal by 99.3 % from the coriander leaves and reduces the drying time by increasing the drying rate (1.44% db/min) as compared to open sun drying (29°C), at all the selected levels of pretreatments and loading densities. Chemically treated coriander leaves dehydrated under a solar greenhouse dryer required 28.6 % less drying time than other treated and dried leaves. Nevertheless, drying methods and loading densities had significant effects, while treatment effects were marginal. It was found that reduction of moisture (due to migration of moisture from inner core to the outer surface followed by evaporation of moisture from the outer surface) and moisture removal rate per unit time occurred mostly in the falling rate period except some accelerated removal of moisture (present in the outer surface) at the beginning up to 150 minutes. Page's model was found most appropriate for drying coriander leaves followed by Generalized exponential model and Lewis model.</p>

Introduction

The coriander (*Coriandrum sativum*) leaves are rich in vitamin A (β – carotene), vitamin C, thiamine, zinc, fibre and low in saturated fat and cholesterol. Fresh coriander leaves consist of 84 % moisture (Bhat *et al.*, 2014). Due to high moisture and improper post-harvest management, the losses in fruits and vegetables were estimated to be 10 - 40 % (Kaya *et al.*, 2007 and El-Sebaei *et al.*, 2012).

Sun drying is traditionally an oldest method to preserve cereals, pulses, fruits, and vegetables, but this method involves quantitative and qualitative losses because of direct exposure to the sun, dirt, soil, insects, microbes, and other biotic factors. Therefore, solar greenhouse drying can be used as an alternative advanced technique to reduce post - harvest losses, maintaining the final qualitative

characteristics of dehydrated goods compared to fresh produce.

Passive solar greenhouse dryer is a covered structure with recommended glazing materials, inside which the crop could be dried due to greenhouse effect. Due to faster removal of moisture under the dryer, drying time is reduced, and better dehydrated product is obtained (Singh *et al.*, 2020a and Singh *et al.*, 2020b). Blanching of vegetables is commonly done to retain the color and texture and inactivation of enzymes such as peroxidase (Oliveira *et al.*, 2016). Kaur *et al.* (2006) also investigated the qualitative parameters of processed vegetables with respect to pretreatments and air temperatures. Loading density (weight of fresh coriander leaves per unit area kept on drying tray) also play an important role in drying of leafy vegetables. Singh *et al.* (2020c) studied the economic viability of solar dryer and found it technically and economically suitable for drying and dehydration of coriander. Jain *et al.* (2000) reported dehydration characteristics of spinach at uniform loading rate of 2 kg/m². Drying characteristics of vegetables and fruits have been reported by several researchers, some of which includes on okra slices (Wankhade *et al.*, 2013), moringa leaves (Ali *et al.*, 2014) and leafy vegetables (Pati *et al.*, 2015). However, thorough investigation of drying properties of coriander leaves using solar greenhouse dryers at different levels of pretreatment and loading densities is not reported so far. Therefore, the present study was focused on the change of moisture content, drying rate, and moisture ratio of coriander leaves inside and outside passive solar greenhouse dryer at different levels of pretreatments and loading densities.

Material and Methods

Materials

Sample: Coriander (cv. Pant Haritma) was arranged from Horticultural Research Centre of Sardar Vallabhbhai Patel University of Agriculture & Technology, Meerut, India, and washed thoroughly in fresh water so as to remove roots and other unwanted materials.

Experimental set-up: A solar greenhouse dryer (5m x 3m x 2.3m) consisted of drying chamber oriented towards east-west direction and covered with 200 micron UV stabilized polyethylene sheet

developed at Horticultural Research Centre of SVP University of Agri. & Tech., Meerut, India was used for present investigation. Other components of solar greenhouse dryer were (i) insulated and black painted floor (ii) 0.13 m wide air inlet opening on south wall, and (iii) L shape (1.5 m length) air outlets on the north wall. Temperature and relative humidity were measured using digital RH/ Temperature recorder (0 to 200 °C, least count: 0.1°C), and 42 °C (RH: 33%) inside the solar greenhouse dryer and 29 °C (RH: 37%) at ambient were observed. The air speed inside and outside the dryer was measured by hot wire anemometer (air flow, model TA5), and the weight of coriander leaves during drying with the help of electronic balance (precision: ±0.1 g).

Methods

Experimental procedure: Dehydration study of washed coriander leaves was conducted as shown in Figure 1. Experiments were performed at three drying conditions considering two levels of drying methods (SGD: solar greenhouse drying and OSD: open sun drying), three levels of pretreatments (CT: Chemical treatment 0.1 % magnesium chloride + 2 % potassium metabisulphate + 0.1 % sodium bicarbonate for 15 min, BW: boiling water treatment of 0.5% Na₂S₂O₅ for 2 min, and UT: untreated i.e. control), and three levels of loading densities (L1: 2.0 kg/m², L2: 2.5 kg/m², and L3: 3.0 kg/m²). These levels of pretreatments and loading densities were chosen as per previous findings (Kaur *et al.*, 2006; Singh, *et al.*, 2006) with three replications at each levels of drying conditions. Pretreated samples with respective loading densities were spread onto trays in single layer of about 10 mm thickness inside and outside the solar greenhouse dryer during day time (10 AM to 5 PM). The samples were weighed at the intervals of 30 min. Afterward, the samples were kept in air tight plastics sheet during night and the samples were again dried on the next day till the completion of dehydration of coriander leaves.

Drying analysis: The method recommended by Ranganna (1986) was used to calculate the moisture content (MC) on % dry basis (% db):

$MC = (W - W_d) \times 100 / W_d$, where W is the weight of sample at any time (g), and W_d the weight of dry material in the sample (g).

The drying rate (DR) was calculated as:

$DR = (M_t - M_{t+\Delta t})/\Delta t$, where M_t is the moisture content of the product at any time t (% db), $M_{t+\Delta t}$ the moisture content at time $t+\Delta t$ (% db) and t the time at any instant (min).

The overall drying rate (ODR) $= (M_o - M_F)/t_T$, where M_o and M_F are initial and final moisture contents (% db), and t_T the total drying time (min).

The moisture ratio (MR) is dimensionless and represents the unaccomplished MC (or moisture):

$MR = (M_t - M_e)/(M_o - M_e)$, where M_t is moisture content of the product at any time, and M_e the equilibrium moisture content. Here M_e values are very less than the values of M_o and M_t , therefore,

M_F was taken in place of M_e . Thus, MR can be simplified as $(M_t - M_F)/(M_o - M_F)$.

Model fitting of drying data: The values of moisture ratios for the samples of coriander leaves were used for testing the following (Table 1) commonly used models and the best fit model was predicted on the basis of R^2 (coefficient of determination) and SEE (standard error of estimation).

Statistical Analysis: The experimental data of dehydrated coriander leaves were analysed graphically using the software viz. EXCEL and MINITAB.

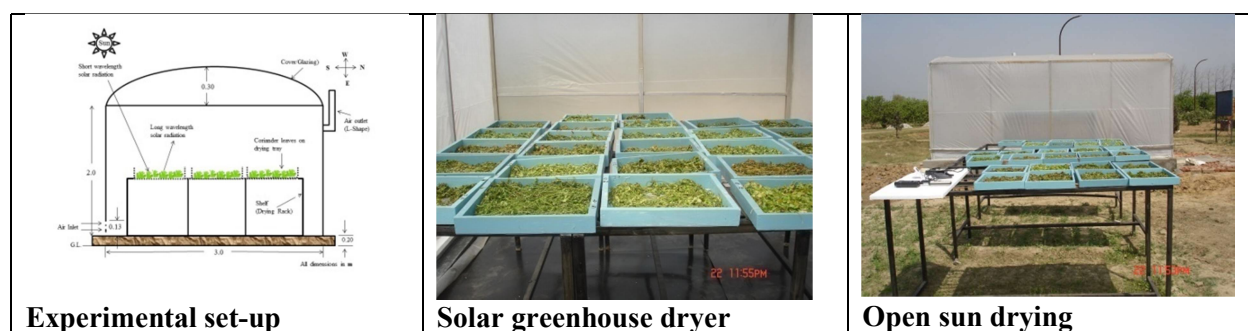


Figure 1: Experimental views of dehydration of coriander leaves.

Table 1: Commonly used mathematical drying models

Model	Name	References
$MR = e^{-kt}$	Lewis model	Bruce, 1985
$MR = e^{-kt^n}$	Page's model	Sarimeseli, 2011
$MR = Ae^{-kt}$	Generalized exponential model	Pande et al., 2000

K: drying constant, A, B and t: equation constants.

Results and Discussion

Moisture Content (MC)

The values of M_o were observed in the range of 627.24 to 714.33% (db). The change in MC with respect to time at different treatments under SGD) and OSD at three levels of loading densities were plotted (Figure 2 to Figure 7). The graphs show non linear relationship between MC and drying time. Initially, MC decreased slowly during first hour because of low temperature in the morning, and very short constant rate period as also observed by Hallstrom *et al.* (2006). Akonor *et al.* (2012) reported longer falling rate period, a phenomenon characteristics of food products. Singh *et al.*, (2017) also observed major part of drying in falling rate

period with exception of some initial acceleration period during of berseem under solar dryer. MC decreased rapidly during the drying period of 60 to 150 min due to warming of inside chamber and absorption of more heat by the product (faster drying) then MC decreased slowly i.e. falling rate period started after 150 min. Due to diffusion of water from inner surface to outer surface, drying took place. During first 60 min of drying, decrease in moisture was 41.55 % and in the next 90 min, the decrease was 322.27 %. During the last 30 min, the reduction of moisture was only 2.32 %. Drying time of 450 min for CT at 2.0 and 2.5 kg/m^2 inside the SGD, and 720 min were observed for boiling water treated at 3.0 kg/m^2 under OSD. The

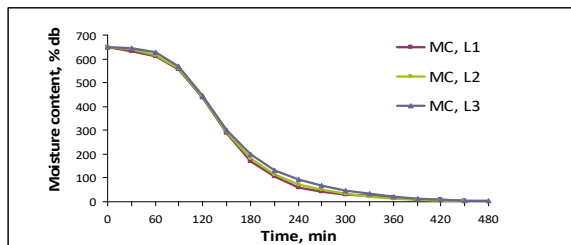


Figure 2: Changes of MC with time under GSD for CT samples.

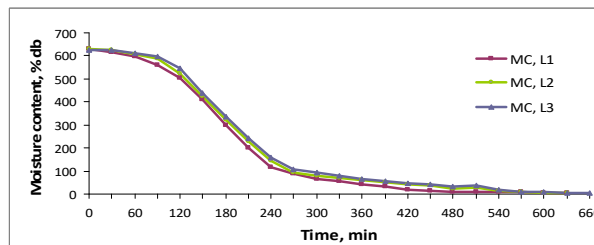


Figure 7: Changes of MC with time under OSD for UT samples.

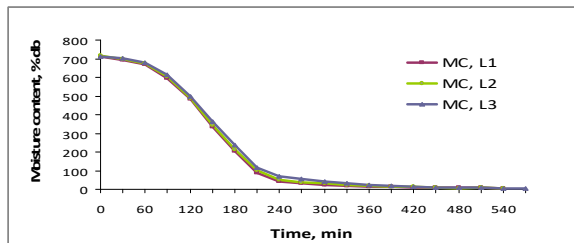


Figure 3: Changes of MC with time under GSD for BW treated samples.

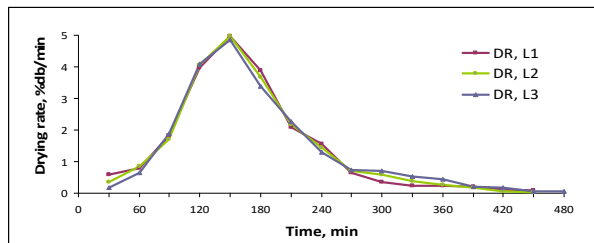


Figure 8: Variation of DR with time under GSD for CT samples.

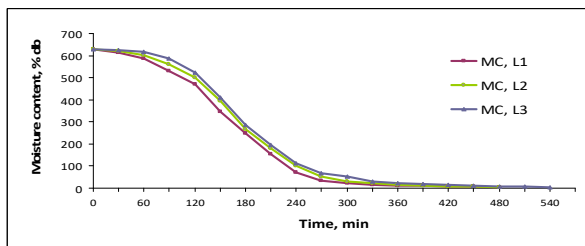


Figure 4: Changes of MC with time under GSD for UT samples.

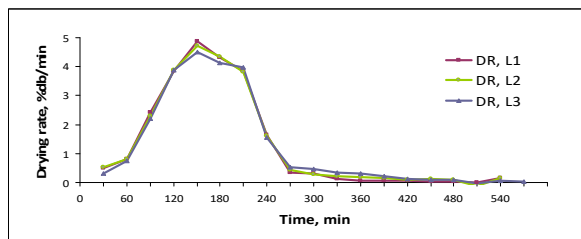


Figure 9: Variation of DR with time under GSD for BW treated samples.

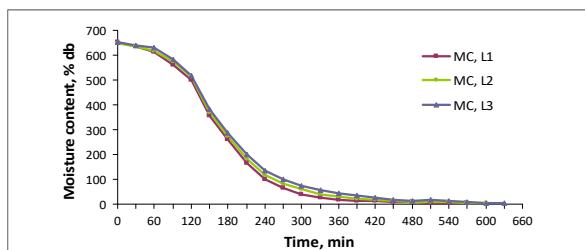


Figure 5: Changes of MC with time under OSD for CT samples.

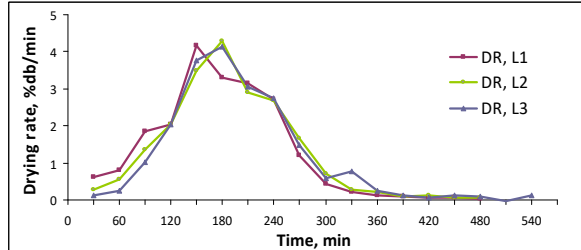


Figure 10: Variation of DR with time under GSD for UT samples.

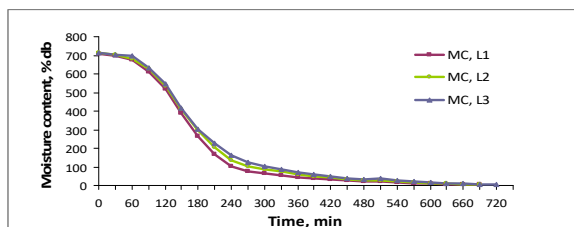


Figure 6: Changes of MC with time under OSD for BW treated samples.

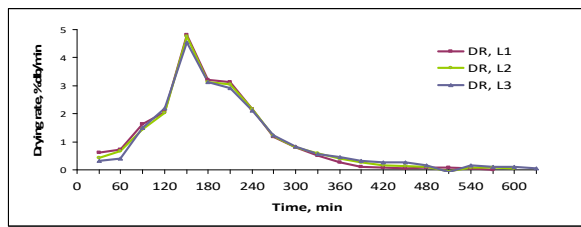


Figure 11: Variation of DR with time under OSD for CT samples.

decreased time of drying with increasing air temperature was also observed by Sehedlou *et al.* (2010) and Ahmad (2013). The time of drying increased also with loading density because of the wider thickness of the drying sample. The drying time of 570 min at 2.0 kg/m², 600 min at 2.5 kg/m² and 630 min at 3.0 kg/m² were observed under OSD for the samples treated with chemical.

Comparing the curves among Figure 2, 3 and 4, it was observed that samples treated with chemical took smallest drying time of 450 min at 2.5 kg/m² under SGD, UT samples took 480 min at 2.5 kg/m² and blanched samples took 540 min at loading density of 2.5 kg/m². Smallest drying time for chemically treated samples under SGD was observed because of faster removal of MC due to facilitation of opening of pore structure which resulted into more absorption of heat and rapid mass transfer. Same trend was observed earlier in green bean by Rosello *et al.* (1997). The decreased MC was attributed to increased evaporation of water both on the surface and inside structure of

coriander due to increasing temperatures by solar heating. As per normal expectation, rapid drying took place at higher temperatures inside the SGD.

Drying Rate (DR)

The DR curves for the convective drying process of coriander leaves are shown in Figure 8 to 13, and the results of overall DR are presented in Table 2. The DR curves show the accelerated DR during initial phase of drying upto 150 minute. The faster heat and mass transfer operation at the beginning causes the accelerated DR due to internal heat generation (Lyons *et al.*, 1972). As expected, the rapid DR was observed at high temperatures inside SGD (Figure 8 to 10) as compared to OSD (Figure 11 to 13). DR was quite low for first hour due to low temperature in the morning. As the temperature inside the drying chamber goes on increasing and when it reaches at its peak temperature, the values of drying rate were observed to be maximum. Maximum part of drying occurred between 120 min to 300 min and during this period, the drying chamber remained at high temperature under SGD.

Table 2: Overall DR at different drying conditions.

Drying methods	Loading density	Treat ment	Initial MC (%db)	Final MC (%db)	Drying time (min)	Overall DR (%db/min)
GSD 42 °C (30-50 °C)	L1 (2.0 kg/m ²)	CT	650.75	4.49	450	1.436
		BW	709.31	4.85	540	1.305
		UT	630.24	4.94	480	1.303
	L2 (2.5 kg/m ²)	CT	649.34	4.92	450	1.432
		BW	714.33	5.02	540	1.314
		UT	627.83	4.87	480	1.298
	L3 (3.0 kg/m ²)	CT	650.35	4.55	480	1.345
		BW	711.25	5.17	570	1.239
		UT	627.24	5.01	540	1.152
OSD 29 °C (22-33 °C)	L1 (2.0 kg/m ²)	CT	650.75	4.482	570	1.134
		BW	709.31	4.87	690	1.021
		UT	630.24	4.977	630	0.992
	L2 (2.5 kg/m ²)	CT	649.34	4.087	600	1.075
		BW	714.33	5.013	690	1.028
		UT	627.83	5.137	630	0.988
	L3 (3.0 kg/m ²)	CT	650.35	4.145	630	1.026
		BW	711.25	4.981	720	0.981
		UT	627.24	5.215	660	0.942

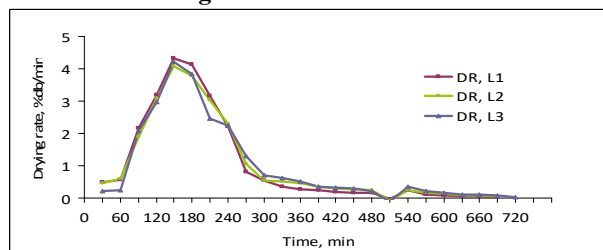
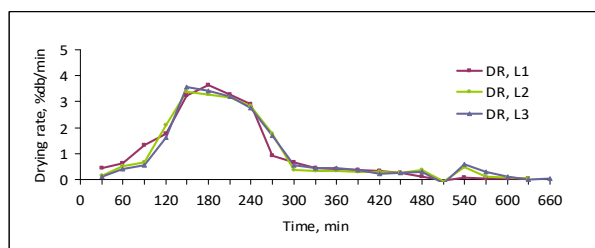
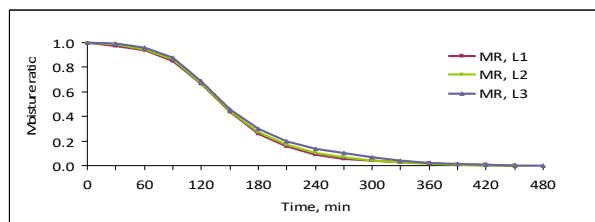
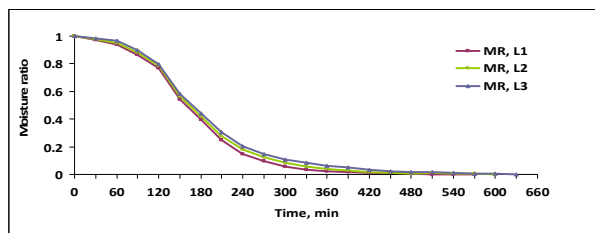
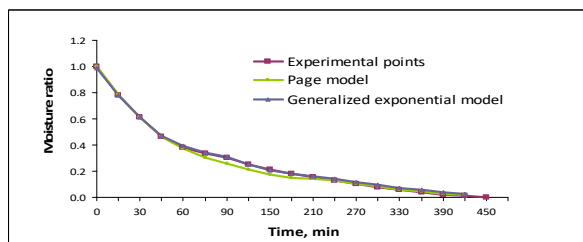
decreased to 0.077% db/min finally. Similar non linear trends of falling rates were also observed in other results for both SGD and OSD conditions.

There were some unexpected interactions due to experimental variations. Effect of temperature on overall DR for coriander leaves was clearly more

Table 3: Analysis of variance for selected drying conditions on overall drying rate.

Source	df	SS	MS	F_c	F_{tab}^*
Drying method	1	0.98	0.98	30.13	4.75
Loading density	2	0.83	0.42	12.74	3.88
Treatment	2	0.19	0.09	2.85	3.88
Error	12	0.39	0.03		

*at 5% level of significance

**Figure 12: Variation of DR with time under OSD for BW treated samples.****Figure 13: Variation of DR with time under OSD for UT samples.****Figure 14: Variation in MR with time under GSD.****Figure 15: Variation in MR with time under OSD.****Figure 16: Performance of drying models for CT samples under SGD at 2.5 kg/m² loading density.**

prominent due to increase in temperature upto 42 °C under SGD as compared to 29 °C under OSD (Table 2). Such findings are in accordance with the observations made by Kumar *et al.* (2011). Kumar *et al.* (2011) mentioned highest drying rate at 75 °C and whole drying process in falling rate period for carrot pomace. The graphs also indicate the absent of constant rate period and occurrence of drying mostly in falling rate period. Garg *et al.* (2014) and Akpinar *et al.* (2003) reported maximum drying in falling rate period for pea pods and apple slices respectively. The main reason of drying was internal mass transfer due molecular diffusion from interior region to upper surface and then evaporation from the surface (Lahsasni *et al.* (2004).

Overall, the DR decreased with increase in loading density and slightly low values for BW treated and UT samples than for CT (Table 2). Faster drying took place for CT samples, as compared to other treatments due to more expansion of the coriander pores treated with chemicals. Table 3 shows the analysis of variance for the selected drying conditions. Significant effect of drying methods and loading densities were observed, however, there was non significant effect of treatments ($P < 0.05$).

Moisture Ratio (MR)

The variations in MR with time for experimental range of temperatures 30 – 50 °C under SGD and 22 - 33 °C under OSD were plotted. A sample graph representing variations in MR with drying time under SGD and OSD for CT samples at three levels of loading densities are given in Figure 14 and Figure 15, respectively. The relationship shows that there was slow decrease in MR during the initial 60 minutes of drying and then rapid decrease in MR during 60 to 150 minutes of drying in all cases. However, in later stage of drying the decrease in MR was at slower rate. The curves, in general

Table 4: Statistical results for selected drying models.

Drying method	Loading density	Pre Treat ment	Lewis Model		Page's Model		Generalized Exponential Model	
			R ²	SEE	R ²	SEE	R ²	SEE
SGD	L1 (2.0 kg/m ²)	CT	0.9928	0.0294	0.9934	0.0291	0.9946	0.0260
		BW	0.9976	0.0162	0.9994	0.0085	0.9990	0.0112
		UT	0.9926	0.0293	0.9946	0.0258	0.9958	0.0228
	L2 (2.5 kg/m ²)	CT	0.9926	0.0295	0.9948	0.0252	0.9960	0.0222
		BW	0.9825	0.0428	0.9936	0.0266	0.9910	0.0312
		UT	0.9928	0.0294	0.9940	0.0273	0.9956	0.0294
	L3 (3.0 kg/m ²)	CT	0.9946	0.0254	0.9974	0.0182	0.9976	0.0176
		BW	0.9944	0.0252	0.9986	0.0131	0.9974	0.0176
		UT	0.9912	0.0317	0.9978	0.0164	0.9958	0.0228
OSD	L1 (2.0 kg/m ²)	CT	0.9914	0.0314	0.9946	0.0256	0.9954	0.0236
		BW	0.9928	0.0287	0.9960	0.0219	0.9964	0.0209
		UT	0.9910	0.0322	0.9942	0.0266	0.9950	0.0245
	L2 (2.5 kg/m ²)	CT	0.9916	0.0322	0.9938	0.0273	0.9948	0.0253
		BW	0.9936	0.0273	0.9972	0.0183	0.9964	0.0208
		UT	0.9932	0.0288	0.9950	0.0248	0.9958	0.0230
	L3 (3.0 kg/m ²)	CT	0.9922	0.0305	0.9944	0.0266	0.9952	0.0244
		BW	0.9898	0.0345	0.9930	0.0291	0.9940	0.0273
		UT	0.9918	0.0311	0.9948	0.0253	0.9954	0.0237

showed continuous decrease of MR with time. Rosell'o *et al.*, (1997) for green bean, Gogus and Maskan (1999) for okra, and Gupta *et al.*, (2002) for red chilli also observed the same trend. Figure 14 shows clear influence of SGD at different levels of loading densities, on the drying time for reduction of MC. MR showed that the drying of samples at 2.0 kg/m² was faster than 2.5 and 3.0 kg/m². Similar trend was observed for other temperature condition under OSD and also for BW treated and UT samples. Figure 14 and 15 shows that due to increase in temperature under SGD, there was rapid decrease in MR as compared to OSD. The time to reduce the MR was maximum at 29 °C under OSD and lowest at 42 °C under SGD. Lowest drying time to reduce the MR was reported for thin layer drying of carrot at highest temperature of 70 °C (Doymaz, 2004).

Validity of Drying Models

Selected models (Table 1) which describe the phenomenon of drying in falling rate period were attempted for their validity and the results are shown in Table 4. The R² and SEE values ranged from 0.9825 to 0.9994 and 0.0085 to 0.0345 respectively, which indicates the similarity in the observed and predicted values. On the basis of R²

and SEE values, it is clear that the generalized exponential model and the Page's model was found most suited in comparison to Lewis model for experimental data. Pande *et al.*, (2000), and Ahmed *et al.*, (2001) reported generalized exponential model and Page's model, respectively as the best fit model for coriander leaves. Further testing of these models was made to decide the best model among all the selected models by plotting the curves of MR with drying time for observed and predicted values (Figure 16). The Page's and generalized exponential model, present over estimation in MR during the first 150 minute during drying and under estimation after 150 minute. Page's model predicted the drying behaviour very closely in later stages of drying. Generalized exponential model also predicted the drying behaviour reasonably in latter stage of drying but closeness with experimental data is more in case of Page model. Therefore, if later stage of drying is considered important than initial stage of drying then Page's model described experimental data most precisely.

Conclusion

The above study concludes that the increased drying temperature under SGD (42°C) reduces the

drying time in comparison to OSD (29°C), at all the selected levels of pretreatments and loading densities. Chemical treated coriander leaves at loading density of 2.5 kg/m² was found to be most suitable for drying. However, significant effect of drying method (SGD and OSD) and loading densities, and non-significant effect of treatment

was observed. Drying of coriander took place mostly in the falling rate period except some accelerated removal of moisture at the beginning, up to 150 minutes. Among three selected drying models, the Page's model fitted well for the data of drying experiment under the study.

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