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Drying kinetics of turmeric rhizomes and mathematical modeling

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ABSTRACT

Drying kinetics of turmeric rhizomes (finger and mother rhizomes) was investigated by two drying methods namely direct sun drying and solar greenhouse drying with two different drying surfaces (black sheet over mud floor and directly on mud floor). The temperature and RH of ambient air and the air inside the solar greenhouse dryer varied from 31 to 47 ºC and 55 to 16 % respectively and 36.5 to 57 ºC and 53 to 14 %, respectively during the study period. The moisture content of boiled finger and mother rhizomes was 567 and 257% (db), respectively. Drying rate of turmeric rhizomes was higher (26.15 g of water/h/100 g of bone dry materials) in solar greenhouse dryer than the direct sun drying (23.64 g of water/h/100 g of bone dry materials). Among the drying surfaces, black sheet over mud floor recorded higher drying rate. Drying time of black sheet covered solar greenhouse dried turmeric finger and mother rhizomes were recorded about 52 and 68 h, respectively and reached an equilibrium moisture content of 7.39 and 10.95% (db), respectively. Six thin layer drying models namely Lewis, Page, Modified Page, Henderson-Pabis, Diffusion approximation and Two-term exponential were tested to identify the most appropriate model to describe drying kinetics of turmeric rhizomes. It was found that among the six drying models, Diffusion approximation and Page models are the best models to describe the drying characteristics of turmeric rhizomes.

Key words: *Curcuma longa*, solar greenhouse dryer, sun drying, equilibrium moisture content, thin layer drying.

INTRODUCTION

Turmeric (*Curcuma longa* L.) plant, a perennial herb belongs to the ginger family *Zingiberaceae*, has primary and secondary rhizomes. The most active component of turmeric is curcumin, which constitutes 2 to 5% of the spice (Kocaadam and Sanlier, 2017). The quality of turmeric powder depends upon the initial quality of rhizomes and the practices adopted during its post harvest operations. Processing of turmeric consists of washing, boiling, drying and polishing of rhizomes, before it is powdered. Drying is one of the most important post harvest unit operations because it determines the quality of the end product (Fig. 1). The main aim of drying of turmeric is to reduce the moisture present in the turmeric, which is 70–80% at the time of harvest to a safe limit of around 10% for grinding or 6% for safe storage (Singh *et al*., 2010). Yield of dry turmeric varies from 20 to 30% depending upon the variety and the region of cultivation (Balakrishnan, 2007). Conventional mechanical driers are beyond the reach of rural people due to their limited product volume and higher financial and energy requirements. Moreover, the increasing rate of fuel consumption in agriculture has made it necessary, not only to save energy by intensifying the drying process, improving designs etc., but also using renewable and freely available energy sources for drying processes, wherever possible.

Sobukola *et al.* (2007) studied the convective hot air drying of blanched yam slices and found the approximation of diffusion model satisfactorily describe the kinetics of air-drying of blanched yam slices. Jayashree and Visvanathan (2012) studied the modeling of drying kinetics of ginger rhizomes and reported that among the models tested, diffusion approximation model represented the thin layer drying behaviour of ginger under sun drying, solar tunnel drying and tray drying in a better way.

Gunasekar *et al*. (2006) reported that for drying of turmeric rhizomes, solar drying is better than direct sun drying as it achieved the desired moisture and essential quality in 64 hours as compared to 96 hours in sun drying. Jose and Joy (2009) revealed that solar tunnel drying method is an effective alternative to traditional direct sun drying, where retention of curcumin, volatile oil and oleoresin was high, with less drying time. Uneven and non-uniform drying promote the microbes, especially fungus, to grow immediately on rhizomes. Jose and Joy (2005) reported that traditional drying method could result in the loss of volatile oil (up to 25%) by evaporation and in the destruction of some of the light-sensitive oil constituents. Thus, choosing the right drying technique is important in the process of drying to improve the quality of the produce. Modeling of drying kinetics of turmeric rhizomes

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Fresh finger rhizomes

Fresh mother rhizomes

Boiled finger rhizomes

Boiled mother rhizomes

Dried finger rhizomes

Dried mother rhizomes

Fig. 1. Turmeric rhizomes after different processing operations.

is very useful to determine the values of different variables and use the same in a drying process without going for actual drying. Therefore, research was undertaken with the objectives to conduct drying studies on turmeric rhizomes using different drying methods and drying surfaces and modeling drying characteristic curves.

MATERIALS AND METHODS

Freshly harvested turmeric mother and finger rhizomes (Erode variety) were collected from a local farmer at Namakkal region, Tamil Nadu, India and used for the study.

Drying of turmeric rhizomes was carried out after the boiling process. Drying studies were conducted at farmer's field by adopting two drying methods namely open sun drying (OSD) and solar greenhouse drying (SGD) and two drying surfaces namely black sheet over mud floor and directly on mud floor to determine the effects of drying methods and drying surfaces on drying time and drying rate of turmeric rhizomes (Fig. 2). A sample size of 2 kg was used for each condition.

The orientation of the solar greenhouse dryer was made east-west direction, since the light transmittance was high in this direction and maximum exposure to solar radiation could be possible. The solar greenhouse dryer having single drying chamber of 2 × 3 × 2 m was used for drying turmeric rhizomes. The chamber was semi cylindrical shaped tunnel constructed using pipe frame structure called hoops. The metallic frame structure of the dryer was covered by a UV stabilized semi-transparent polyethylene sheet of 200 micron thickness having 90 per cent transmissivity. The UV stabilized sheet was transparent to the short wave radiations and opaque to long wave radiations. During the sunshine hours, the short wave radiations were entrapped through the UV stabilized sheet, heated the absorber (black sheet) and got converted into long wave radiations. As the long wave radiations were not allowed to escape out of the plastic sheet of the solar greenhouse dryer and retransmitted back to the absorber and this increased the temperature inside the dryer and helped for quick drying of turmeric rhizomes. A curtain type door of 1.6 m height and 1 m wide made of transparent UV stabilized sheet was provided in the front of the solar greenhouse dryer. Natural air current was used to ventilate the dryer. Nylon mesh, having an area of 400 × 800 mm size was fixed at the bottom end of the door which allowed the outside atmospheric air to enter and move faster through the dryer, reduced its humidity. Nylon mesh (400 × 800 mm) was also provided at the top to a height of 30 cm above the door which acted as a chimney.

Finger and mother rhizomes samples with an initial moisture content of 566.67 % and 257.14 % (db), respectively were spread uniformly in a thin layer on 30 × 30 cm floor area and the same procedure was followed using black sheet having a thickness of 2.5 mm and dried under open sun and inside the solar greenhouse dryer until constant moisture content was reached. Drying was stopped when constant weight was achieved. The temperature, relative humidity and wind velocity of ambient air and air inside the solar greenhouse dryer were recorded at every two hours interval during drying using digital thermometer, hygrometer (Lutron HT-3003) and hot wire anemometer ("AM - 4201"), respectively. The sun and solar drying studies were started simultaneously and the values were recorded from 1 P.M. to 5 P.M. on the first day as the boiling of rhizomes was over only by 1 P.M. and from the second day onwards from morning 9 A.M to evening 5 P.M. The parameters for plotting the drying characteristic curves were calculated as given below.

Fig. 2. Drying studies on turmeric rhizomes.

Moisture content of turmeric rhizomes was determined by toluene distillation method (ASTA, 1968). The moisture content was estimated as given below.

$$M = \frac{V_w}{W_s} \times p_w \times 100 \qquad (1)$$

where, M is the moisture content, (wb, %), V_w is the volume of water collected in trap, (cm^3), W_s is the weight of the sample (g), ρ_w is the density of water, (g cm^{-3}).

The moisture content of turmeric rhizomes in dry basis was determined as follows

$$M_{db} = \frac{W_m}{W_d} \times 100 \qquad (2)$$

where, M_{db} is the moisture content (db, %), W_m is the mass of moisture present in the sample (kg), W_d is the weight of dry matter present in the sample (kg).

The drying rate for turmeric was determined as follows (Karthikeyan and Murugavelh, 2018).

$$DR = \frac{M_{t+dt} - M_t}{t} \qquad (3)$$

Where, M_t is the moisture content at time t, % (db) and t is the drying time (h)

The moisture ratio was calculated as (Téllez et al., 2018)

$$MR = \frac{M - M_e}{M_o - M_e} \qquad (4)$$

where, MR is the moisture ratio, dimensionless value, M is the moisture content at time t, % (db), M_o is the initial moisture content, % (db), M_e is the equilibrium moisture content, % (db).

The moisture content data collected during different experiments were converted into moisture ratio (MR) expression and plotted against drying time. The thin-layer drying models given in the Table 1 were tested to determine the best fit model for describing the drying process.

Table 1. Thin-layer drying models applied to describe drying kinetics of turmeric rhizomes.

Model name	Model	Reference	
Page	$MR = \exp(-kt^n)$	Lopez *et al*. (2000)	...(5)
Modified Page	$MR = \exp(-(kt)^n)$	Ozdemir and Devres (1999)	...(6)
Diffusion approximation	$MR = a\exp(-kt) + (1-a)\exp(-kbt)$	Ertekin and Yaldiz (2004)	...(7)
Two-term exponential	$MR = a\exp(-kt) + (1-a)\exp(-kat)$	Ertekin and Yaldiz (2004)	...(8)
Lewis model	$MR = \exp(-kt)$	Roberts *et al*. (2008)	... (9)
Henderson–Pabis model	$MR = a\exp(-kt)$	Roberts *et al*. (2008)	...(10)

Nonlinear regression procedure was performed on all drying curves to estimate the parameters associated with the six selected models using the software Sigma Plot (ver 6.0). The coefficient of determination R^2 was the primary criterion for selecting the best fit model to describe the drying curve. In addition, the goodness of fit for each model was evaluated based on root mean square error (RMSE) and chi square (χ^2). The best model describing the drying kinetics of turmeric rhizomes was chosen as the one with the highest R^2 value, the lowest RMSE value followed by the lowest $\div^2$ value. The predicted moisture ratio was compared with the experimental moisture ratio using root mean square error and chi square as shown in the following equations (Lakshmi *et al*., 2018).

$$R^2 = 1 - \frac{\sum_{i=1}^{N}\left(MR_{pre,i} - MR_{exp,i}\right)^2}{\sum_{i=1}^{N}\left(\overline{MR}_{pre} - MR_{exp,i}\right)^2} \qquad (11)$$

$$\chi^2 = \frac{\sum_{i=1}^{N}\left(MR_{exp,i} - MR_{pre,i}\right)^2}{N-n} \qquad (12)$$

$$RMSE = \sqrt{\frac{1}{N}\sum_{i=1}^{N}\left(MR_{pre,i} - MR_{exp,i}\right)^2} \qquad (13)$$

Where $MR_{exp,i}$ and $MR_{pre,i}$ are the i^{th} experimental and predicted moisture ratios and $\overline{MR}_{pre}$ is the average predicted moisture ratio. *N* is the number of observations and *n* is the number of constants in a model.

RESULTS AND DISCUSSION

Temperature and relative humidity of ambient air varied from 31 to 47 ºC and 55 to 16 %, respectively during the study period. Temperature and relative humidity of the air inside the solar greenhouse dryer varied from 36.5 to 57 ºC and 53 to 14 %, respectively. The wind velocity ranged between 0.1 and 3.6 m/s in the open air and inside the solar greenhouse dryer it ranged between 0 to 0.5 m/s. Every evening, the turmeric samples were cooled and packaged in an air tight container and kept inside a closed house.

The moisture content of boiled finger and mother rhizomes was found to be 566.67 and 257.14 % (db), respectively. The finger rhizomes dried under direct sun light on two different drying surfaces namely, black sheet over mud floor and directly on mud floor recorded a total drying time of 70 and 78 hours and reached an equilibrium moisture content of 9.55 and 9.78 % (db), respectively, whereas mother rhizomes recorded a total drying time of 88 and 96 hours and attained an equilibrium moisture content of 12.38 and 13.03 % (db), respectively. In the case of solar greenhouse drying, the above mentioned two drying surfaces recorded a total drying time of 52 and 56 hours to dry the boiled finger rhizomes and reached an equilibrium moisture content of 7.39 and 7.54 % (db), respectively. Mother rhizomes dried inside the solar greenhouse dryer over the above said two drying surfaces took only 68 and 74 hours to dry the rhizomes and attained an equilibrium moisture content of 10.95 and 11.05 % (db), respectively (Fig.3).

These results may be due to the higher temperature of air inside the solar greenhouse dryer (5-10˚C higher than outside air). Here, UV sheet acted like a trapping cover and not allowed the reradiated solar energy in the form of long waves to escape from the dryer. As no trapping mechanism was available over rhizomes under direct sun drying, the long wave radiations radiated from the earth surface and black sheet were lost to the atmosphere and hence recorded lower drying temperature and higher equilibrium moisture content as compared to solar greenhouse drying. As compared to finger rhizomes, mother rhizomes recorded higher equilibrium moisture content in both drying methods and drying surfaces. This may be due to the more thickness of mother rhizomes and more number of fibrous roots present on the surface of mother rhizomes. Gunasekar *et al*. (2006) studied the drying characteristics of turmeric rhizomes and reported that it took 96 hours and 64 hours in sun drying and solar drying, respectively, to get the

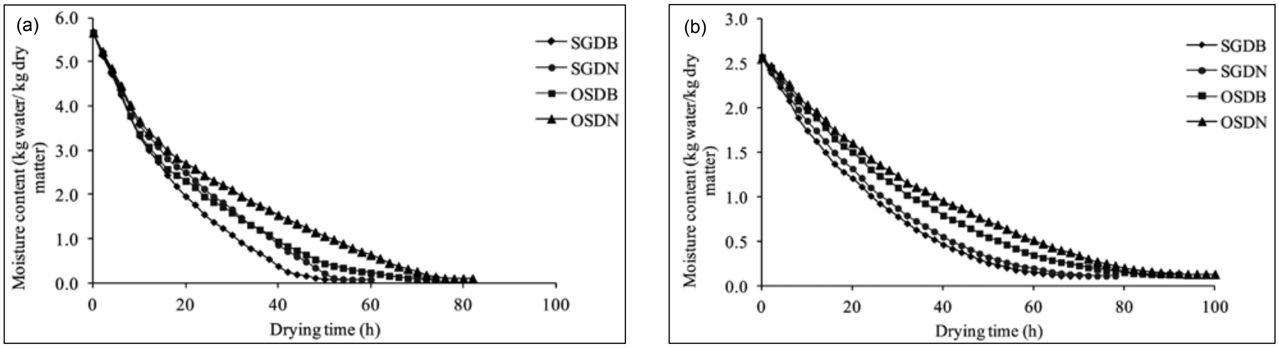

Fig. 3. Drying curves of turmeric rhizomes. (a) finger rhizomes and (b) mother rhizomes.

turmeric rhizomes at around 7 % (w.b.) (6.54 %, db) moisture content. The drying data recorded are in line with the results reported by Gunasekar *et al*. (2006).

Turmeric rhizomes dried on black sheet over mud floor and directly on mud floor both under direct sun drying and solar greenhouse drying showed a continuous increase in the drying rate from morning to till1 P.M. and then showed a decreasing trend till the end of the day. This trend was observed during the initial drying and started decreasing slowly till it reached the equilibrium moisture content. Among the different drying methods studied, inside the solar greenhouse dryer the drying rate is higher than the direct sun drying irrespective of the drying surfaces studied both for finger and mother rhizomes (Fig. 4). This may be due to the fact that the UV sheet cover provided in the solar greenhouse dryer trapped and returned the reradiated solar energy in the form of long waves back to the surface which resulted in higher temperature inside the dryer. Lower drying rate of rhizomes dried under direct sun drying is due to the prevailing lower air temperature since much of the heat was lost to the surroundings from the drying surfaces in the form of reradiation. Among the drying surfaces studied, black sheet over mud floor recorded higher drying rate in both the drying methods for finger and mother rhizomes. This is due to the heat absorption and emission properties of the black sheet.

Reduction in the drying rate at the end of drying is mainly due to reduction in moisture content as drying advances. As the moisture content decreased at the final stage of drying the rate of diffusion of moisture from inner surface to outer surface also decreased and hence recorded lower drying rates. As compared to finger rhizomes, mother rhizomes recorded lower drying rates in all the drying methods and drying surfaces studied. This may be due to the harder texture and presence of hairy roots on the surface of the mother rhizomes. Suganya *et al.* (2013) reported that the drying rate of glory lily beans was higher inside the poly house than the direct sun drying and among the drying surfaces studied, beans dried on black sheet over concrete floor recorded higher drying rates than the beans dried directly on concrete floor. In the present study also the turmeric rhizomes dried on black sheet over mud floor recorded higher drying rates than the rhizomes dried directly on mud floor and the drying rate of rhizomes was higher inside the solar greenhouse dryer than the direct sun drying.

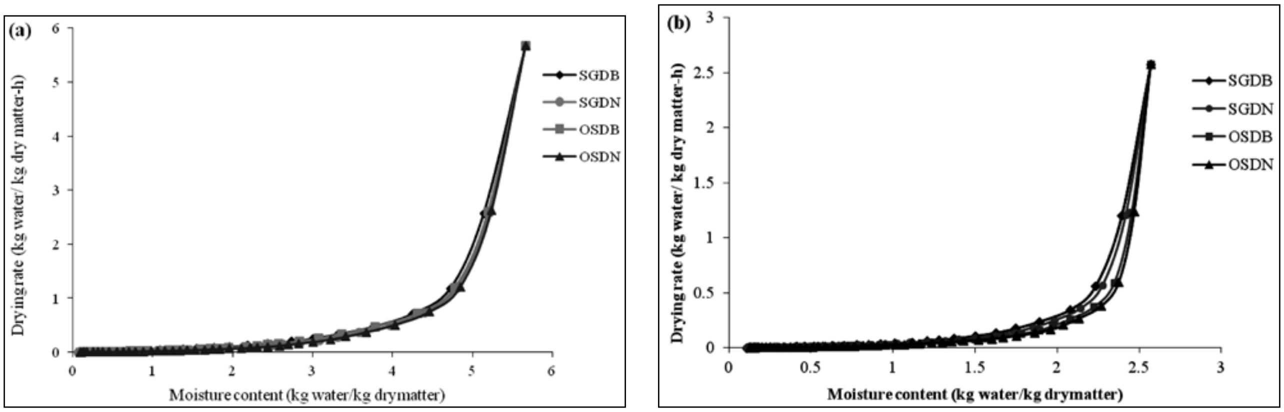

Fig. 4. Drying rate curves of turmeric rhizomes. (a) finger rhizomes and (b) mother rhizomes.

Relationship between moisture ratio and drying time for turmeric rhizomes dried under direct sun and solar greenhouse drying on black sheet over mud floor and on mud floor is depicted in Fig. 5. It was observed that irrespective of drying methods and drying surfaces adopted, i.e. in all drying experiments, there was a continuous decrease of the moisture ratio with drying time. It indicates that diffusion mechanism mainly governed the water movement in the samples (Doymaz, 2012).

The models used were Diffusion approximation, Henderson-Pabis, Lewis, Modified Page, Page and Two-term exponential. The best model describing the drying kinetics of turmeric rhizomes was chosen as the one with the highest R^2 value, the lowest RMSE value followed by the lowest χ^2 value.

The moisture ratio expression of turmeric finger rhizomes dried inside the solar greenhouse dryer on black sheet over mud floor was tested with above said six different models and the empirical drying constants pertaining to each model, the statistical parameters like R^2, RMSE, and χ^2 for estimating the goodness of fit for the above said models were calculated and are summarized in Table 2.

The coefficients of determination (R^2) for the drying rate constants of all six thin-layer drying models were above 0.98, with two being above 0.99. These high coefficients of determination are due to the highly linear plots of the unaccomplished moisture content, which are perhaps due to accurate equilibrium moisture contents.

From table 2, it was observed that among the models tested, diffusion approximation model may be assumed to represent the thin layer drying behaviour of turmeric finger rhizomes dried inside the solar greenhouse dryer on black sheet over mud floor and on mud floor and dried under direct sunlight on mud floor. It was also found to fit better for turmeric mother rhizomes dried inside the solar greenhouse dryer on black sheet over mud floor and under direct sun light on mud floor. Page model best fitted for the finger and mother rhizomes dried under direct sun light on black sheet over mud floor and for mother rhizomes dried inside the solar greenhouse dryer on mud floor. The best fit models for different drying conditions are given below

For finger rhizomes dried inside the solar greenhouse dryer on black sheet over mud floor (Diffusion approximation)

$$\mathrm{MR} = \frac{M - M_e}{M_o - M_e} = -4.1631e^{(-0.0976t)} + (1 + 4.1631)e^{(-0.0866t)} \tag{14}$$

For finger rhizomes dried inside the solar greenhouse dryer on mud floor (Diffusion approximation)

$$\mathrm{MR} = \frac{M - M_e}{M_o - M_e} = -2.8208e^{(-0.0759t)} + (1 + 2.8208)e^{(-0.0656t)} \tag{15}$$

For finger rhizomes dried under direct sun light on black sheet over mud floor (Page model)

$$\mathrm{MR} = \frac{M - M_e}{M_o - M_e} = e^{-0.0442t^{1.0282}} \tag{16}$$

For finger rhizomes dried under direct sun light on mud floor (Diffusion approximation)

$$\mathrm{MR} = \frac{M - M_e}{M_o - M_e} = 0.0374e^{(-0.4314t)} + (1 - 0.0374)e^{(-0.0359t)} \tag{17}$$

For mother rhizomes dried inside the solar greenhouse dryer on black sheet over mud floor (Diffusion approximation)

$$\mathrm{MR} = \frac{M - M_e}{M_o - M_e} = -4.7830e^{(-0.0788t)} + (1 + 4.7830)e^{(-0.0704t)} \tag{18}$$

For mother rhizomes dried inside the solar greenhouse dryer on mud floor (Page model)

$$\mathrm{MR} = \frac{M - M_e}{M_o - M_e} = e^{-0.0176t^{1.2499}} \tag{19}$$

For mother rhizomes dried under direct sun light on black sheet over mud floor (Page model)

$$\mathrm{MR} = \frac{M - M_e}{M_o - M_e} = e^{-0.0138t^{1.2462}} \tag{20}$$

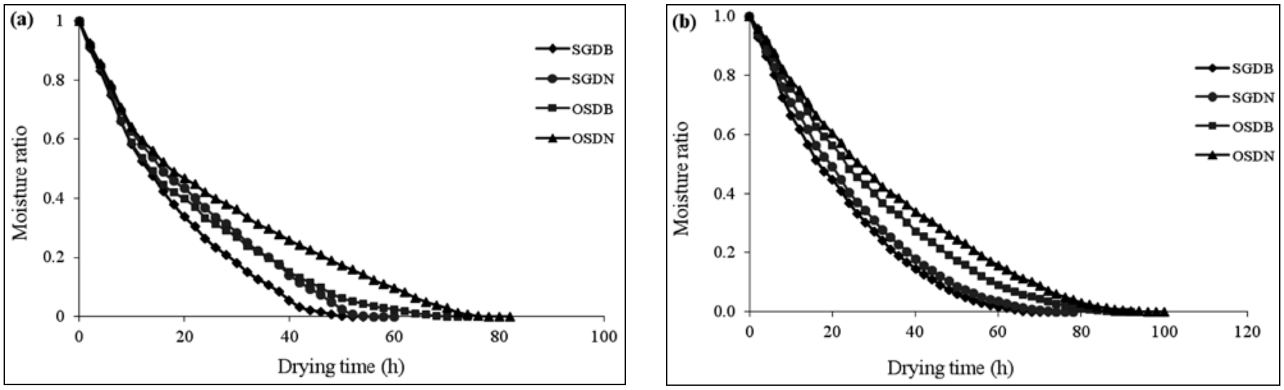

Fig. 5. Moisture ratio curves of turmeric rhizomes. (a) finger rhizomes and (b) mother rhizomes.

Table 2. Statistical results of thin-layer drying models for different solar dried turmeric rhizomes (finger and mother).

*Drying method	Model	Model constant		R^2		RMSE		χ^2	
		Finger	Mother	Finger	Mother	Finger	Mother	Finger	Mother
SGDB	Diffusion approximation	k = 0.0976; a = -4.1631 b = 0.8875	k = 0.0788; a = -4.7830; b = 0.8930	0.9952	0.9962	0.0204	0.0182	0.0005	0.0004
	Henderson-Pabis	k = 0.0599; a =1.0442	k =0.0476; a =1.0523	0.9895	0.9889	0.0303	0.0310	0.0010	0.0010
	Lewis	k =0.0574	k =0.0453	0.9873	0.9859	0.0334	0.0350	0.0012	0.0013
	Modified Page	k =0.3788; n= 0.1515	k =0.3365; n= 0.1346	0.9873	0.9859	0.0334	0.0350	0.0012	0.0013
	Page	k =0.0341; n= 1.1703	k =0.0236; n= 1.1976	0.9949	0.9959	0.0210	0.0188	0.0005	0.0004
	Two term exponential	k =26.7272; a = 0.0021	k =23.5013; a =0.0019	0.9870	0.9857	0.0337	0.0352	0.0012	0.0013
SGDN	Diffusion approximation	k = 0.0759; a = -2.8208 b = 0.8641	k = 0.0753; a = -5.1910; b = 0.8882	0.9874	0.9968	0.0321	0.0170	0.0012	0.0003
	Henderson-Pabis	k = 0.0473; a =1.0264	k =0.0436; a= 1.0668	0.9826	0.9867	0.0379	0.0345	0.0015	0.0013
	Lewis	k =0.0461	k =0.0410	0.9816	0.9820	0.0388	0.0401	0.0016	0.0017
	Modified Page	k =0.3395; n= 0.1358	k =0.3202; n= 0.1281	0.9816	0.9820	0.0389	0.0401	0.0016	0.0017
	Page	k =0.0305; n= 1.1277	k = 0.0176; n = 1.2499	0.9865	0.9968	0.0333	0.0170	0.0012	0.0003
	Two term exponential	k =12.9643; a = 0.0035	k =10.8584; a =0.0037	0.9814	0.9814	0.0391	0.0408	0.0016	0.0018
OSDB	Diffusion approximation	k = 0.5024; a = -0.0064 b = 0.097	k = 0.0611; a = -5.1801; b =0.8890	0.9923	0.9958	0.0243	0.0192	0.0006	0.0004
	Henderson-Pabis	k = 0.0487; a =1.0045	k =0.0356; a= 1.0686	0.9923	0.9861	0.0243	0.0352	0.0006	0.0013
	Lewis	k =0.0484	k =0.0334	0.9923	0.9810	0.0243	0.0410	0.0006	0.0017
	Modified Page	k =0.3480; n= 0.1392	k =0.2891; n= 0.1156	0.9923	0.9810	0.0243	0.0410	0.0006	0.0018
	Page	k = 0.0442; n = 1.0282	k = 0.0138; n = 1.2462	0.9926	0.9959	0.0239	0.0192	0.0006	0.0004
	Two term exponential	k =4.2949; a = 0.0111	k = 8.8906; a =0.0037	0.9920	0.9804	0.0247	0.0417	0.0006	0.0018
OSDN	Diffusion approximation	k = 0.4314; a = 0.0374 b = 0.0832	k = 0.0529; a = -4.6405; b = 0.8816	0.9876	0.9936	0.0298	0.0236	0.0010	0.0006
	Henderson-Pabis	k = 0.0365; a =0.9792	k =0.0310; a =1.0646	0.9872	0.9842	0.0303	0.0372	0.0010	0.0014
	Lewis	k =0.0373	k =0.0291	0.9866	0.9795	0.0310	0.0423	0.0010	0.0018
	Modified Page	k =0.3054; n= 0.1222	k =0.2698; n= 0.1079	0.9866	0.9795	0.0310	0.0423	0.0010	0.0019
	Page	k =0.0400; n= 0.9800	k =0.0122; n= 1.2337	0.9868	0.9936	0.0308	0.0237	0.0010	0.0006
	Two term exponential	k =1.1454; a = 0.0315	k =7.3533; a =0.0039	0.9874	0.9789	0.0300	0.0430	0.0009	0.0019

*SGDB: solar greenhouse dryer with floor covered by black sheet, SGDN: solar greenhouse dryer with floor not covered by black sheet, OSDB: open sun drying with floor covered by black sheet, OSDN: open sun drying with floor not covered by black sheet.

For mother rhizomes dried under direct sun light on mud floor (Diffusion approximation)

$$MR = \frac{M - M_e}{M_o - M_e} = -4.6405e^{(-0.0529t)} + (1 + 4.6405)e^{(-0.0466t)} \qquad (21)$$

where,
MR - moisture ratio
t - drying time, min

Validation of the selected model was done by comparing the predicted moisture ratio values with the experimental moisture ratio values at different drying time (Fig. 6).

A good agreement was observed between the experimental and predicted moisture ratio values. *Jayashree and Visvanathan (2012) studied the*

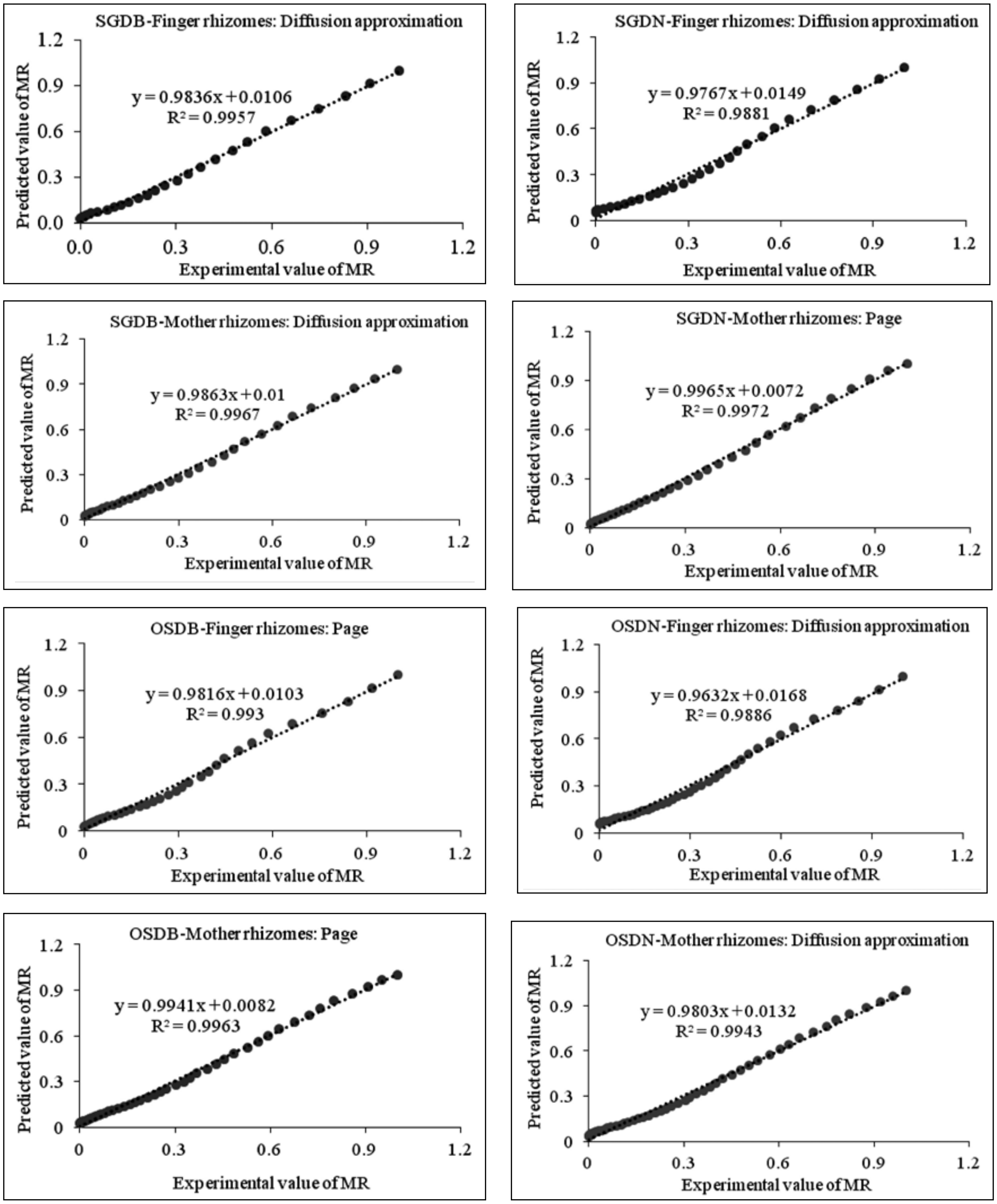

Fig. 6. Comparison of the experimental and predicted values of moisture ratio of turmeric rhizomes dried under different drying methods and floor surfaces.

mathematical modeling for thin layer drying of ginger in a multi-rack type solar tunnel drier and reported that the diffusion approximation model best described the 'over all' drying process of ginger in a solar tunnel drier. Sobukola *et al.* (2007) studied the convective hot air drying of blanched yam slices and reported that among the nine drying models, the approximation of diffusion model was found to satisfactorily describe the kinetics of air-drying of blanched yam slices. This confirms the findings of present study.

Turmeric rhizomes were dried using different drying methods and drying surfaces. Boiled turmeric finger and mother rhizomes dried on black sheet over mud floor inside the solar greenhouse dryer recorded minimum equilibrium moisture content of 7.39% (db) and 10.95% (db), respectively at relatively short drying time of 52 and 68 hours respectively. Among the six drying models tested, Diffusion approximation and Page models better described the drying characteristics of turmeric finger and mother rhizomes dried on black sheet over mud floor and directly on mud floor under direct sun drying and solar greenhouse drying in a better way.

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