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Development of empirical expression for the groundnuts drying inside a greenhouse

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Abstract

The single layer drying of groundnut samples was investigated in a greenhouse under natural and forced convection modes. The groundnuts were dried to final moisture level to 8-10% (w.b.). Four mathematical models were compared to describe the groundnut drying process. The performance of single layer drying models was studied by comparing the statistical parameters such as root mean square error (RMSE), reduced chi square (χ^2), coefficient of correlation (R), and mean bias error (MBE) between predicted and experimental moisture ratios. Lewis model was observed to give the uppermost value of 'R' (0.99072 – 0.99766) and lowermost values of 'χ^2' (0.05833 – 0.08984), 'RMSE' (0.08310 – 0.11118) and 'MBE' (0.00806 – 0.01279) for groundnut drying inside a greenhouse under both the natural and forced convection modes. Therefore, Lewis model was observed to be best for describing the drying performance of groundnuts under natural (NCGHD) and forced (FCGHD) convection greenhouse modes.

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Introduction

Groundnut/Peanut *(Arachis hypogaea),* is one of the most important oilseed crop in India (Misra *et al*., 2000; Sahdev *et al*., 2016). It is highly rich in protein (20-50%), fat (40-50%) and edible oil (43-55%) (Sahdev *et al*., 2015). Its food value in terms of protein, carbohydrate, fat and calorific value is better than milk, egg, mutton, beef, red gram etc. (Talawar, 2004; Sahdev *et al*., 2018a). It was originated in South America and then spread to Brazil and now is grown in all sub-tropic and tropic nations in the world. It came into existence in India in sixteen century. India contributes 14.83% share of groundnut production in the world (USDA, 2017) and ranks second (6.3 metric million tons) in the production of groundnut followed by China (17 metric million tons). Indian groundnut is very famous because of its taste, flavour and crunchiness. The exports of Indian groundnuts have reached about 5.38 metric million tons during 2015-2016 (APEDA, 2017).

Demand of food in the world is increasing with the reckless rise in the population. Agricultural land is also being converted into commercial buildings which further reduces the agricultural land and hence produce. The losses of agricultural products during post-harvest processes are also reported to be about 40% (El-Sebaii and Shalaby, 2012; Sahdev *et al*., 2018b). Hence, the urgent need is felt to save the agriculture products from post-harvest losses. Groundnuts (highly nutritious crop), during post-harvest, required to be dried to its safe storage moisture level of 8-10% (w.b.) (Sahdev *et al*., 2015), or it will be infected with the fungus. Drying (moisture removal process from the interior of the product) is one of the most significant post-harvest process to hinder the growth of fungi. Farmers commonly use open sun drying (OSD) to dry groundnuts in which product is spread on ground under solar radiations. OSD, obviously, is the cheapest among all drying methods, but products dried under OSD are not meeting the international standards because of its limitations such as uncontrolled drying, discolouring due to ultraviolet radiations, dust, birds, animals etc. The losses during post-harvest process can be minimised by using proper and advanced drying method reduces the drying time as well as increases its quality. An advanced drying technique, i.e., greenhouse drying can be adopted which overcomes the limitations of OSD and improves the product quality. The product, under greenhouse drying, is placed in trays and receives the solar radiations through the UV plastic sheet and the moisture from the product is removed by natural or forced mode.

Simulation models are also very helpful in designing a new dryer or in improving an existing

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dryer for the drying of agricultural products. Many researchers have carried out the studies on the mathematical modelling and experimental studies on single layer drying phenomenon of different commodities are summarized in Table 1.

It is found, from the vast literature, that the information on thin layer drying behaviour of groundnut under greenhouse is not available. Therefore, this study has been undertaken to fulfil the existing gap on thin layer modelling of groundnut. The chief objectives of this research are (a) to study the drying kinetics of groundnut in greenhouse drying under natural (NCGHD) and forced (FCGHD) convection modes, and (b) to study the most suitable drying model to describe the drying behaviour of groundnuts under given conditions.

This study would be very helpful to predict the single layer drying behaviour of groundnut under NCGHD and FCGHD conditions.

Materials and Methods

Experimental set-up and instrumentation

An even span roof type greenhouse of 120×80 cm^2 active floor area was made-up of plastic pipe and an Ultra Violet film cover of two hundred microns. It's central and wall heights were kept as 60 cm and 40 cm respectively. An air vent of 20×20 cm^2 (for natural mode) was provided at the roof for air out. A fan (1340 rpm, 5 m/s rated velocity and 22.5 cm sweep diameter) was installed on the east side wall of the FCGHD condition. The orientation of greenhouse was kept east-west for maximum utilization of solar radiations. The experimental set up was located on the roof of a two floor building to get the maximum exposure to solar radiations.

For each mode of drying, groundnut samples in single thin layer were kept in a rectangular wire mesh tray of sizes 0.15×0.25 m^2 (Sample 1), 0.25×0.40 m^2 (Sample 2) and 0.35×0.60 m^2 (Sample 3). An electronic digital weighing balance (Smart: made in India, capacity: 6 kg, least count: 0.1 g) was used for measuring the mass of moisture evaporated. The wind velocity was measured with an anemometer (Lutron: AM-4201, least count: 0.1 m/s^2). The difference of two successive readings of the weighing balance gave the water evaporated during that time interval and was used in the determination of moisture ratio (MR).

Sample preparation and experimental procedure

Fresh groundnuts were procured from the farmer and cleaned to remove immature and broken pods. Groundnut samples required for experimentation

Table 1. Summary of thin layer drying phenomenon of various commodities

S. No.	Author and year	Commodity	Drying method	Suggested model
1	Basunia and Abe, 2001	Rough rice	Natural convection solar grain dryer	Page model
2	El-Sebaii *et al.* (2002)	Seedless grapes, figs, green peas, tomatoes and onions	Indirect type natural convection solar dryer	Empirical model by El-Sebaii *et al.*
3	Akpinar *et al.* (2004)	Apricots	Indirect forced convection solar dryer	Midilli-Kucuk model
4	Doymaz (2004)	Carrot	Cabinet dryer	Page model
5	Prakash and Tiwari (2005)	Concentrated sugar-cane juice	NCGHD and FCGHD	Exponential model
6	Doymaz (2006)	Mint leaves	Cabinet dryer	Logarithmic model
7	Sacilik *et al.* (2006)	Organic tomato	Solar tunnel dryer	Diffusion model
8	Goyal *et al.* (2007)	Blanched (1% KMS)Plum	Tunnel dryer	Logarithmic model
9	Sacilik (2007)	Hull-less seed pumpkin	Solar tunnel, open sun and hot air drying	Logarithmic model
10	Yang *et al.* (2007)	Peanut	Trailer-type dryer	Henderson-Pabis, Hummeida, and modified Oswin EMC model
11	Akbulut and Durmus (2009)	Mulberry	Solar cabinet dryer	Midilli model
12	Dissa *et al.* (2009)	Mango slices	Solar dryer	Drying model by Dissa *et al.*,
13	Koua *et al.* (2009)	Plaintain banana, mango and cassava	Direct solar dryer	Henderson and Pabis model
14	Kituu *et al.* (2010)	Tilapia fish	Solar tunnel dryer	Drying model by Kituu *et al.*,
15	Kumar *et al.* (2011)	Khoa	OSD, NCGHD and FCGHD	Exponential model
16	Jayashree and Visvanathan (2012)	Ginger	Solar tunnel dryer (STD)	Diffusion approximation model
17	Akoy (2014)	Mango slices	Convection air dryer	Page model
18	Khawas *et al.* (2014)	Kachkal banana peel	Convective air dryer	Modified Page model
19	Panwar (2014)	Kasuri methi	STD	Verma *et al.* model
20	Sansaniwal and Kumar (2015)	Ginger	Natural convection indirect solar dryer	Modified Page model
21	Dejchanchaiwong *et al.* (2016)	Natural rubber sheets	ISD and mixed mode solar dryer	Hii *et al.* model
22	Faneite *et al.* (2016)	Green plantain peel	Hot air drying	Modified Henderson-Pabis model
23	Nag and Dash (2016)	Elephant apple	Laboratory scale tray dryer	Two term exponential model
24	Onwude *et al.* (2016)	Pumpkin slices	Convective hot air dryer	Hii *et al.* model
25	Vijayan *et al.* (2016)	Bitter gourd slices	Indirect solar dryer (ISD) and open sun drying (OSD)	Two term and Midilli–Kucuk model.
26	Dhanushkodi *et al.* (2017)	Cashew	Solar biomass hybrid dryer	Page model

were remoistened by soaking in water for twelve hours and then conditioned in shed for one hour to remove the extra moisture. The experiments were performed during April, 2016 in the weather conditions of Rohtak (28°54'N 76°34'E), India. Wire mesh tray of sizes 0.15×0.25 m^2 (Sample 1), 0.25×0.40 m^2 (Sample 2) and 0.35×0.60 m^2 (Sample 3) were used to accommodate the groundnut samples over the digital weighing balance. Observations were recorded hourly. The two consecutive values of weighing balance directly gave the water evaporated during that time interval. The groundnut samples were dried up to the safe storage moisture level of 8 – 10% (w.b.).

The experimental data obtained for the groundnut weight were used for the drying kinetics of groundnut in terms of moisture removal rate. The moisture content data for both experimental modes were converted into moisture ratio (MR) and were used for different drying models as defined below:

a. Lewis model (Lewis,1921): $MR = \exp(-k \times t)$
b. Page model (Page, 1949): $MR = \exp(-k \times t^n)$
c. Modified Page model (Yaldiz *et al.*, 2001): $MR = \exp\left[(-k \times t)^n\right]$
d. Henderson and Pabis model (Henderson and Pabis, 1961): $MR = a \exp(-k \times t)$

Where *'a'* and *'n'* are constants (dimensionless) and *'k'* is the drying constant (1/h), *'t'* is the time (hrs). The MR of groundnut during drying was estimated by Equation (1) (Dejchanchaiwong *et al.*, 2016)

$$MR = [M_t - M_e]/[M_i - M_e] \tag{1}$$

Where *'M_t'* is the moisture content at drying time (% d.b.), *'M_i'* is the initial moisture level (%, d.b.), 'M_e' is the equilibrium moisture level (% d.b.), The root mean square error (RMSE), reduced chi square *(χ^2)*, coefficient of correlation *(R)*, and mean bias error (MBE) were considered to be the primary criterion to define the consistency of the best single layer drying model. These parameters can be evaluated using Equations (2) to (5) (Shringi *et al.*, 2014; Kumar, 2016)

$$R = \frac{N \times \sum_{i=1}^{N} MR_{\exp,i}\, MR_{pre,i} - \left(\sum_{i=1}^{N} MR_{\exp,i}\right)\left(\sum_{i=1}^{N} MR_{pre,i}\right)}{\sqrt{N \times \sum_{i=1}^{N} MR_{\exp,i}^{2} - \left(\sum_{i=1}^{N} MR_{\exp,i}\right)^{2}}\sqrt{N \times \sum_{i=1}^{N} MR_{pre,i}^{2} - \left(\sum_{i=1}^{N} MR_{pre,i}\right)^{2}}} \tag{2}$$

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

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

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

Where $MR_{exp,i}$ is the experimentally calculated moisture ratio (MR) and $MR_{pre,i}$ is the predicted MR for the model. *N* and *n* are the number of observations and constants respectively. The model suitability was evaluated by considering the higher value of R and least values of RMSE, χ^2, and MBE. The drying rate, i.e., DR was defined as the amount of moisture evaporated over time and is evaluated using Equation (6) (Meisami-asl and Rafiee, 2009):

$$DR = \frac{M_{t+dt} - M_t}{dt} \tag{6}$$

Where *'M_t'* is the moisture content at drying time *'t'* and *'M_{t+td}'* is the moisture content at drying time *'t+dt'*.

Results and Discussion

The data obtained from experiment for the groundnut samples under natural (NCGHD) and forced convection greenhouse drying (FCGHD) conditions are depicted in Table 2.

The groundnut samples were dried to the final safe storage moisture level of 8–10% (w.b.). Moisture ratio data of NCGHD and FCGHD of groundnuts were investigated to the four drying models and the statistical parameters such as R, χ^2, RMSE and MBE along with their constants are summarized in Table 3.

The variation of MR with respect to 't' the drying time for the drying of groundnut samples under NCGHD and FCGHD are shown in Figure 1.

Similarly the deviation of drying rate regarding drying time for the drying of groundnut samples under NCGHD and FCGHD are shown in Figure 2.

From Table 3, Lewis model with highest value of R (0.99072 – 0.99678) and lowest values of χ^2 (0.06416 – 0.07948), RMSE (0.010056 – 0.11118) and MBE (0.01112 – 0.01413) was observed to be best fit to describe the single layer drying behaviour of groundnut sample under NCGHD mode. It is also seen from Table 3 that in most of the cases under Lewis model, the values of R, is more than 0.99, and least values of RMSE, χ^2 and MBE showing a good fit for the drying of groundnut samples under FCGHD mode. Hence, Lewis model may be considered to characterise the single layer drying behaviour of groundnut under NCGHD and FCGHD modes. Groundnut drying under both modes of greenhouse occurred in the falling drying period from initial to final moisture content.

From Figure 2, drying rate (DR) was found to be increased with the increase in mass of groundnut sample under both greenhouse drying modes. The drying rate during groundnut drying under FCGHD

Table 2. Experimental data for groundnut drying under NCGHD and FCGHD modes

Time	NCGHD Mode						FCGHD Mode					
	Sample 1		Sample 2		Sample 3		Sample 1		Sample 2		Sample 3	
t	Wt.	MR	Wt.	MR	Wt.	MR	Wt.	MR	Wt.	MR	Wt.	MR
(hrs)	(g)		(g)		(g)		(g)		(g)		(g)	
0	193.5	1	518.0	1	1086.0	1	194.4	1	518.0	1	1086.0	1
1	183.7	0.86483	494.5	0.86297	1050.3	0.89522	178.6	0.76627	471.9	0.71349	963.7	0.64684
2	170.1	0.67724	462.1	0.67405	975.3	0.67508	168.4	0.61538	447.4	0.56122	889.7	0.43315
3	155.4	0.47448	433.0	0.50437	910.9	0.48606	157.2	0.4497	424.0	0.41579	849.7	0.31764
4	141.9	0.28828	405.6	0.34461	859.1	0.33402	148.2	0.31657	403.4	0.28776	819.7	0.23101
5	133.3	0.16966	387.3	0.2379	821.3	0.22307	139.2	0.18343	388.4	0.19453	794.7	0.15882
6	127.6	0.09103	377.2	0.17901	796.3	0.14969	131.2	0.06509	379.2	0.13735	780.7	0.11839
7	123.1	0.02897	365.7	0.11195	779.3	0.09979	126.8	0	373.2	0.10006	768.7	0.08374
8	121.0	0	359.3	0.07464	766.3	0.06164	-	-	367.4	0.06401	757.7	0.05198
9	-	-	353.5	0.04082	758.3	0.03816	-	-	362.4	0.03294	751.7	0.03465
10	-	-	348.4	0.01108	751.6	0.01849	-	-	358.4	0.00808	744.7	0.01444
11	-	-	346.5	0	745.3	0	-	-	357.1	0	739.7	0

Table 3. Modeling of MR for thin layer drying of groundnut samples under NCGHD and FCGHD modes

Samples	Model	k	n	a	R	$RMSE$	χ^2	MBE
				NCGHD				
Sample 1	Lewis	-0.22858			0.99072	0.11118	0.06416	0.01413
	Page	0.16873	0.51682		0.95401	0.38680	0.30606	0.19949
	Modified Page	0.00710	0.11520		0.71461	0.28621	0.13186	0.10922
	Henderson and Pabis	0.48451		1.51624	0.94491	0.19454	0.03402	0.05046
Sample 2	Lewis	0.20026			0.99678	0.10056	0.07818	0.01112
	Page	0.05479	0.34651		0.94743	0.62682	0.55039	0.48022
	Modified Page	0.01639	0.21969		0.84068	0.33143	0.23880	0.13425
	Henderson and Pabis	0.40897		1.51356	0.96895	0.16392	0.03796	0.03284
Sample 3	Lewis	0.20326			0.99403	0.10785	0.07948	0.01279
	Page	0.05315	0.35731		0.94553	0.63620	0.55683	0.49469
	Modified Page	0.01596	0.22194		0.83657	0.34378	0.24766	0.14444
	Henderson and Pabis	0.39749		1.41174	0.97193	0.12818	0.02442	0.02008
				FCGHD				
Sample 1	Lewis	0.24106			0.99439	0.08310	0.05833	0.00806
	Page	0.33940	0.38862		0.92030	0.23848	0.16383	0.07962
	Modified Page	0.08492	0.08581		0.74326	0.20646	0.00990	0.05968
	Henderson and Pabis	0.41858		1.26781	0.97259	0.11771	0.01607	0.01940
Sample 2	Lewis	0.22816			0.99766	0.09535	0.08984	0.01000
	Page	0.02555	0.26674		0.95826	0.70948	0.64581	0.61523
	Modified Page	0.01639	0.21969		0.84455	0.24637	0.16082	0.07418
	Henderson and Pabis	0.42268		1.35044	0.98814	0.12008	0.03317	0.01762
Sample 3	Lewis	0.25390			0.98805	0.10938	0.01316	0.09963
	Page	0.01688	0.21341		0.96550	0.75405	0.69494	0.69788
	Modified Page	0.96847	-0.03204		0.84815	0.18824	0.04331	0.09468
	Henderson and Pabis	0.38720		1.03709	0.99877	0.02612	0.00855	0.00083

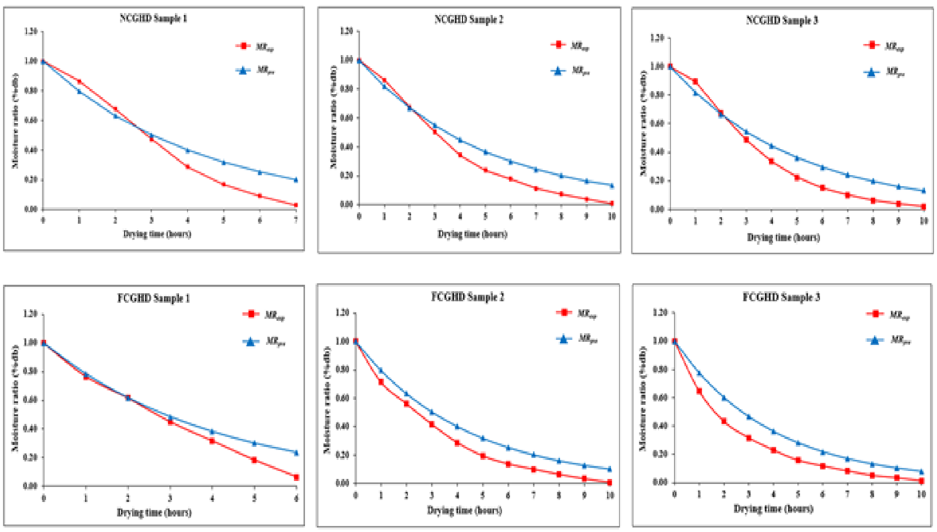

Figure 1. Variation of moisture ratio with respect to drying time for the drying of groundnut samples under NCGHD and FCGHD modes

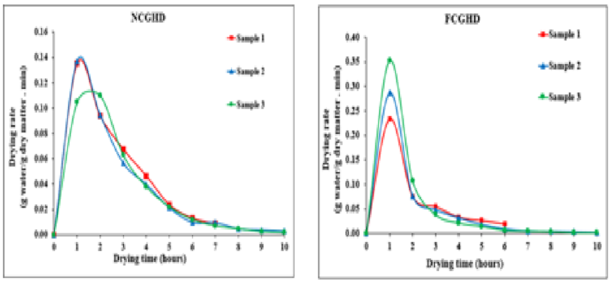

Figure 2. Variation of drying rate with respect to drying time for the drying of groundnut samples under NCGHD and FCGHD modes

was found to be higher than the groundnut drying under NCGHD. This indicates that the time required to dry the groundnut under FCGHD is shorter.

Conclusion

In this research paper, the single layer drying behaviour of groundnuts was studied under natural (NCGHD) and forced convection greenhouse drying (FCGHD) modes. The groundnuts were dried from initial (38% w.b.) to safe storage moisture level of 8-10% (w.b.) under both NCGHD and FCGHD conditions. The entire drying process was found to occur in falling rate period. Lewis model was found to be the best fit model to describe the thin layer drying behaviour of groundnut for both greenhouse drying modes. Drying rate during FCGHD was reported to be higher which resulted in shorter drying time. The greenhouse drying is the low capital investment dryer with zero emission and energy requirement as compared to other conventional drying methods. The present study would be considered for describing the single layer drying behaviour of groundnuts under given conditions.

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