Effect of drying temperature on drying kinetics and quality of spring groundnut (*arachishypogaea* L.)

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Abstract: Groundnut pods contain a higher amount of moisture i.e., 40% – 50% (wet basis) at the time of harvesting which causes fungal infestation and drying play an important role to achieve a safe moisture content. The objective of the present study was to examine the effect of drying temperature on the drying behavior and acceptability of models of drying to prophesy the drying pattern of the groundnut pods. Forced air circulation hybrid convective cum solar dryer and sun drying method was used to dry the groundnut pods from initial moisture of 124.97%±1.34% (dry basis) to a moisture content of 8.75%±0.35% (dry basis). Five mathematical models were used to forecast the drying kinetics and furthermore, moisture diffusivity was determined. The different physico-chemical parameters viz., moisture content, free fatty acids, oil content, protein, ash and colour value were ascertained before and after drying of the pods. It was observed that the drying time was less for the mechanical drying method and the best-suited model for thin layer drying of groundnut pods was the logarithmic model. The higher value of R^2 (0.984) and lower values of SSE (0.0015) and RMSE (0.0391) was achieved in the page model for the open sun drying method. The value of effective moisture diffusivity was highest (7.1517×10^{-10} m^2s^{-1}) for a 70°C mechanical dryer. The quality parameters like oil, protein, and free fatty acids were increased after the drying process irrespective of dying temperature and method, but the increment was more pronounced at 70°C.

Keywords: groundnut pods, drying kinetics, quality, and moisture diffusivity

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1 Introduction

Groundnut *(Arachishypogaea* L.*)*, also known as earth nuts, goober peas, pea nuts, pygmy nuts, and monkey nuts, is a significant oilseed crop. Groundnut is cultivated in the tropic regions of the country. The world production of groundnut was around 46.01 MT during the year 2018-19 (Anonymous, 2020) and the third most important legume in the world.

India holds first rank in the world in terms of area (40% of the total area in the world) and second rank in terms of production (14% of the world's production) (Anonymous, 2020).

Groundnut is generally grown in rain-fed regions and is available all through the year in India. The total area of cultivation and production of groundnut crop is 1000 $hayear^{-1}$ and 3000 MT respectively in Punjab (Anonymous, 2019). The advantage of short duration and high-yielding variety of groundnut such as spring groundnut TG37A, is come up as a highly favorable third crop in the yearly crop cycle.

At the time of harvesting of groundnut crop, the pods contain higher moisture content i.e., about 40%-50% (wet basis), which needs to be reduced immediately after harvesting to a safe level of moisture content for storage (8%-10% wet basis) just after the harvesting (Sahdev, 2015; Kaur et al., 2022;

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Kaur et al., 2023). Fungal infestation may take place on groundnut pods if the safe storage moisture is not achieved immediately after harvesting by fungal species *Aspergillus flavus* and *A. parasiticus*, which further produce aflatoxins i.e., highly toxic mycotoxins (Singh et al., 2022; Kaur et al., 2022; Kaur et al., 2023). The kernel as a whole is highly digestible and consumed salted and either fried or roasted. The groundnut protein's biological value is equal to casein and the highest amongst the vegetable protein. Vegetable ghee is primarily manufactured from groundnut oil, a rich source of vitamin E, riboflavin, thiamin, and nicotinic acid. The oil content in groundnut seeds ranges from 35%-50%, depending on agronomic conditions and varieties (Anonymous, 2019). Due to the semi-perishability of groundnut, during storage, various quality losses like flavor changes and physico-chemical changes occur because of the insects, rodents, and mycotoxins. Moisture plays an important role in development of off-flavors and mycotoxins and further deteriorates of quality with time and an increase in relative humidity (Singh et al., 2022). From previous research work it has been observed there is not enough information available on the thin layer drying behavior of groundnut in open sun drying and mechanical drying. Modeling of the drying process and development of mathematical relations are needed to design the groundnut dryer. According to the demand and need the present study was outlined to examine the influence of drying method and temperature on drying kinetics and quality of groundnut pods and to determine the fitness of thin layer drying models.

2 Materials and methods

2.1 Groundnut samples

The kernels of spring groundnut variety TG37A were procured from Punjab Agricultural University farm. Clean and healthy grains were selected for the study. The initial moisture content of groundnut pods was measured by the standard method (AOAC, 2000).

2.2 Drying of groundnut pods

The drying of groundnut pods in a thin single layer was carried out in a hybrid solar convective dryer at a temperature of 50°C, 60°C and 70°C and using the traditional open sun drying method (control) at observed average temperature and relative humidity of 40.5°C ±5°C and 57%±15%, respectively during the drying period. Mechanical drying was a continuous process and open sun drying was dependent on the solar hours of the day. The samples were spread in 1.5 and 2 cm thickness in the trays uniformly for all methods of drying. The relative humidity and temperature of ambient air were measured using the thermo-hygrometer (288 CTH made by HTC) at a regular interval of 2 h for all the samples. The dryer consists of both solar heating rods and electric heaters of 40 A consisting of 4 heating rods. The drying chamber consists of 14 trays in two columns with a difference of 10.5 cm in two trays. The drying temperature was set using a temperature regulator of TC 19 model made by Multispan. During the absence of bright hours, the dryer was operated using the connected power source.

The loss in moisture content of groundnut pods was calculated by weighing the sample every 2 h, until 8%-10% moisture content was attained. Thermocouples were attached to the control panel to measure the temperature and humidity digitally and at 2 h intervals, readings for both the temperature and humidity were recorded. The drying characteristics like moisture content, moisture ratio, and drying rate were calculated and the drying rate curve was plotted to determine the drying parameters of the samples. The following Equation 1 is used to calculate the moisture ratio (*MR*) given by Yaldiz et al. (2001) and Equation 2 is used to calculate the drying rate.

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

Where,

M = moisture content at a specific time (%);

M_o = initial moisture content (%).

$$Drying\ rate\left(kg\ H_2O/\ m^2.\ sec\right) = -\frac{DM}{A} \times \frac{dX}{dt} \tag{2}$$

Where,

DM = weight of bone-dry sample (kg);

A= area of the sample being dried (m^2);

dX/dt = slope of the graph between free moisture content and time at various points of time in units of kg water per kg of bone-dry sample per second.

Drying data was determined in triplets for each experiment.

2.3 Thin layer air convective drying modeling

Five mathematical models for describing the kinetics of groundnut pod drying were selected from the models used by Obumseli et al. (2018) and are shown in Table 1. The best fitting of these five drying models was verified based on statistical parameters such as R^2, SSE, and RMSE. The goodness of fit is achieved at more than 0.95 value of the R^2 (Doymaz and İsmail, 2011) and lower values of RMSE and SSE (Sacilik et al., 2006). Constants in the mathematical models were determined for the best fit by regression analysis by SPSS version 11.5.

Table 1 Selected thin layer drying models

S. No.	Name of the model	Model equation	References
1.	Newton’s model	$MR = Exp\ (-kt)$	Roberts et al. (2008)
2.	Page	$MR = Exp\ (-kt^n)$	Rafiee et al. (2008)
3.	Henderson and pabis	$MR = a\ Exp\ (-kt)$	Sawhney et al. (1999)
4.	Logarithmic	$MR = a\ Exp\ (-kt) + b$	Akpinar et al. (2006)
5.	Wang and Singh	$MR = 1 + at + bt^2$	Wang and Singh (1978)

*Note: *k*, *a*, *b* and *n* are constants.

2.4 Determination of effective moisture diffusivity

The ability of dehydration during the drying of the sample is determined by effective moisture diffusivity (Dadalı et al., 2007a; Wang et al., 2007). In the present study, some assumptions were made that the groundnut pods have uniform moisture content, the geometry of infinite cylinder, constant moisture diffusivity, negligible shrinkage and external resistance to moisture in the product during the drying process and no internal and external effect of heat transfer (Bansal et al., 2015). According to Doymaz et al. (2006) by plotting *ln* (MR) versus drying time gives *k* as slope and Equation 3 given by Obumseli et al. (2018) was used to determine the effective moisture diffusivity.

$$k = \frac{\pi^2 Deff^{\,t}}{4l^2} \tag{3}$$

Where,

D_{eff} = effective diffusivity (m^2s^{-1});

l = characteristic length, thickness (m);

t = drying time (s).

2.5 Statistical analysis

Five thin layer drying models were used to fit the drying curves and statistical parameters i.e., coefficient of determination (R^2), root mean square error (RMSE), and sum square error (SSE) was determined using Equation 4 and 5 for the best fit.

$$SSE = \frac{\sum (MR_t - MR_e)^2}{n} \tag{4}$$

$$RMSE = \left[\frac{\sum (MR_t - MR_e)^2}{n}\right]^{1/2} \tag{5}$$

Where,

MR_t = theoretical drying ratio;

MR_e = experimental drying ratio;

n = number of observations.

2.6 Determination of physico-chemical properties

Different quality parameters i.e., moisture content, protein content, free fatty acid and ash content were determined using standard AOAC (2000) methods. The standard hot air oven method was used to determine the moisture content of samples (AOAC, 2000). The total oil content of the groundnut pods was measured after extracting the oil using the Soxhlet apparatus. The protein content was measured by the Kjeldahl method (AOAC, 2000).

Color Reader CR-10 colorimeter (Konica Minolta Sensing Inc.) was used to measure the color of the samples (Hunter, 1975). The groundnut samples were placed in the petri dish and placed in the colorimeter and no natural light was allowed to pass in the sample during the measuring process. The color values i.e., 'L', 'a', and 'b' values were recorded at D 65/10º for each sample. The total color change was calculated using Equation 6 given by Dadalı et al. (2007b) below:

$$Colour\ change = [(L-L_0)^2 + (a-a_0)^2 + (b-b_0)^2]^{1/2} \quad (6)$$

Where,

L and L_0 = final and control Lightness value;

a and a_0 = final and control Red/green coordinate

b and b_0 = final and control Yellow/blue coordinates.

3 Result and discussion

3.1 Drying of groundnut pods

The average initial moisture content of the pods was 124.97% ± 1.34% (db). The moisture content was continuously decreased with an increase in drying time in all the drying methods. The drying behavior of groundnut is shown in Figure 1 by plotting a graph between moisture content and drying time. The time taken for moisture content to be constant in mechanical drying and open sun drying is shown in Table 2. A significant effect had been observed on drying tome of drying.

As shown in Figure 1, a non-linear relationship was observed between moisture and drying time. Moisture content was observed to decrease with an increase in the drying time although distinct curves were observed for different drying temperatures. The drying time was minimum i.e., 18 h in case of drying using 70ºC air temperature and the maximum drying time of 24 h was taken by open sun drying to reach the desired moisture content. The results observed in this study were found similar to results obtained in the work done by Obumseli et al. (2018).

The maximum drop in the moisture content was during the initial 6 h of the drying time giving a steeper slope in all the drying methods. The first falling rate period was from 0 – 6 h of the drying time, reducing the moisture content to 49.11%±0.72%, 45.12%±0.90%, 39.10%±0.87% and 50.53%±1.24% (db) in 50ºC, 60ºC and 70ºC and open sun drying, respectively. It was observed that the second falling rate period was shorter (6-10 h of drying time) for 70ºC mechanical drying as compared to 50ºC (6-14 h of drying time), 60ºC (6-12 h of drying time) and sun drying (6-16 h of the drying time). These results were found same to results of Akoy (2014).

Table 2 Time required for drying of groundnut at different temperatures

S. No.	Drying method	Drying air temperature (ºC)	Drying time (h)
1.	Mechanical drying	50	22 h
		60	20 h
		70	18 h
2.	Open sun drying	35±3.5 – morning (9-12) and evening (4-5) 45±2.5 – (Afternoon 12-4 pm)	24 h

*Note: the data recorded during the experimental studies.

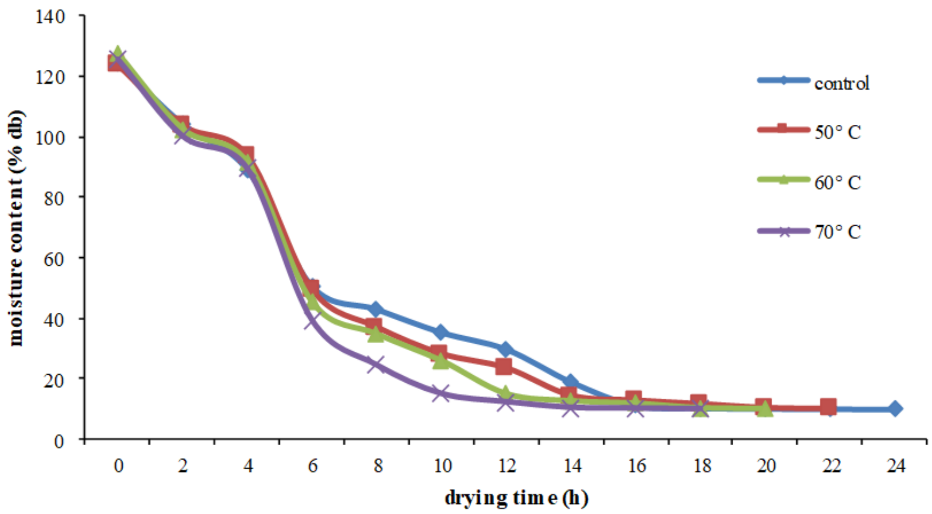

Figure 1 Effect of drying temperature on moisture content of groundnut

3.2 Effect of drying temperature on moisture ratio

Moisture ratio was used to calculate the remaining moisture at any instant of drying. The change in the moisture profile of pods with drying time was given in the terms of moisture ratio versus time of drying for both mechanical and open sun drying methods as shown in Figure 2.

The value of the moisture ratio was observed to decrease with time for all the drying methods as shown in Figure 2. The decrease in moisture ratio was on account of the decrease in the moisture content of the pods as the drying proceeded as reported by Bansal et al. (2015). The drop in the value of the moisture ratio was fastest in 70°C mechanical drying. This was because of the rapid decrease in moisture content of pods using 70°C mechanical drying also reported by Obumseli et al. (2018).

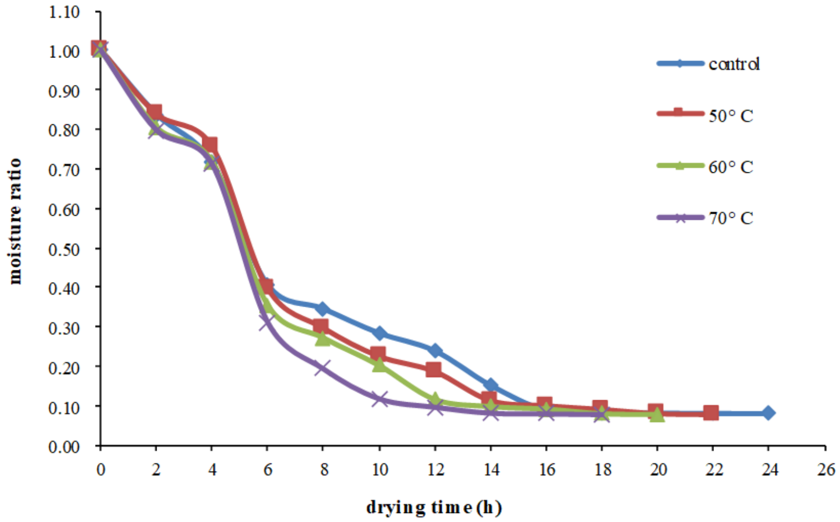

Figure 2 Effect of drying temperature on moisture ratio of groundnut

3.3 Effect of drying temperature on drying rate

The changing trends of the drying rate of pods with drying time is presented in Figure 3. The maximum drying rate values for 50°C, 60°C, and 70°C mechanical and open sun drying methods were 0.369, 0.385, 0.419 and 0.321 kg $H_2Om^{-2}s^{-1}$, respectively. For all the samples, the drying rate was observed to decrease during drying and the reason of the decrease could be reduction in the available moisture at the surface owing to lower moisture diffusion from the center to the surface of the dried pods as also observed by Bansal et al. (2015). As shown in Figure 3, drying rate curve of the open sun drying method has more variations before a complete decrease in drying rate because of the variations in the drying temperature at different times of the day. In general, 70°C drying has higher drying rate values because the drying temperature was higher resulting in higher heat transfer potential between air and groundnut pods as reported by Bansal et al. (2015).

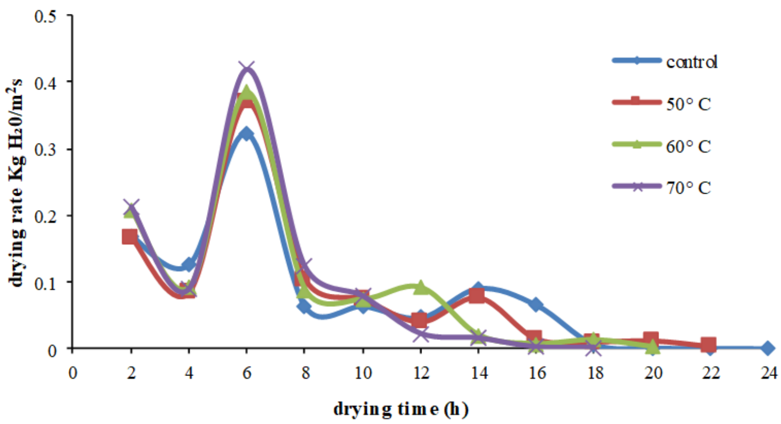

Figure 3 Effect of drying temperature on drying rate of groundnut

3.4 Validation of thin layer drying models

The data obtained from the drying experiments for different drying temperatures was fitted into the selected five thin layer drying models. The statistical analysis values were also summarized in Table 3. The good fit was observed at R^2 values more than 0.95. The page model presented the higher value of R^2 and lower RMSE and SSE at 70°C as shown in Table 3. Thus, the page model represented the thin layer drying characteristics in the best fit. The model expression of the page model representing the thin layer drying model for 70°C is given below in Equation 7.

$$MR = Exp\ (-kt^n) \tag{7}$$

Where,

k and n = constant;

t = drying time (h).

Table 3 Statistical parameters for the models analyzed in groundnut pod drying

Drying method	Model No.	Model Name	Goodness of fit R^2	SSE	RMSE
Mechanical 50 ℃	1.	Newton's model	0.964	0.0036	0.0601
	2.	Page	0.975	0.0025	0.0499
	3.	Henderson and Pabis	0.969	0.0031	0.0560
	4.	Logarithmic	0.969	0.0031	0.0560
	5.	Wang and Singh	0.975	0.0032	0.0566
Mechanical 60 ℃	1.	Newton's model	0.964	0.0036	0.0603
	2.	Page	0.976	0.0024	0.0489
	3.	Henderson and Pabis	0.968	0.0033	0.0571
	4.	Logarithmic	0.968	0.0032	0.0567
	5.	Wang and Singh	0.977	0.0099	0.0994
Mechanical 70 ℃	1.	Newton's model	0.945	0.0062	0.0784
	2.	Page	0.970	0.0034	0.0582
	3.	Henderson and Pabis	0.950	0.0055	0.0745
	4.	Logarithmic	0.952	0.0054	0.0733
	5.	Wang and Singh	0.967	0.0062	0.0786
Open sun (Control)	1.	Newton's model	0.979	0.0019	0.0438
	2.	Page	0.984	0.0015	0.0391
	3.	Henderson and Pabis	0.982	0.0017	0.0413
	4.	Logarithmic	0.982	0.0017	0.0413
	5.	Wang and Singh	0.983	0.0169	0.130

*Note: the data observed from fitting of thin layer drying models.

3.5 Effective moisture diffusivity of groundnut pods

The effective moisture diffusivity of food materials has a general range of 10^{-11} to 10^{-10} m^2s^{-1} (Madamba et al., 1996). The calculated values of the effective moisture diffusivity along with the slope k are shown in Table 4. A slight difference was observed between the effective moisture diffusivity in mechanical drying at 50°C, 60°C, and 70°C and open sun drying methods. The value of D_{eff} was observed maximum in mechanical drying at 70°C because the activity of water molecules increased as the heating energy increased (Akoy, 2014). The observed values of slope k are negative because ln MR and drying time are inversely proportional as shown in Figure 4.

Table 4 Model parameters for groundnut

Drying method T(℃)	*k*	D_{eff} (m^2s^{-1})
50 ℃	-0.1289	5.7341×10^{-10}
60 ℃	-0.1438	6.3395×10^{-10}
70 ℃	-0.1637	7.1517×10^{-10}
Control	-0.1203	5.5214×10^{-10}

*Note: the data observed from experimental calculations

3.6 Effect of drying temperature on quality parameters of groundnut

Different quality parameters i.e., protein content, oil content, free fatty acid and color change of fresh and dried groundnut samples were determined and shown in Table 5. It was observed from the table that oil content, free fatty acids, and protein content increased after the drying of groundnut pods. The increase was observed to be more pronounced in 70ºC drying. This was because the decrease in moisture content increased the experimental value of these properties as also recorded by Aydin (2007). The ash content was observed to decrease with the drying of groundnut pods. The decrease was more before drying because the raw groundnut was rich in mineral resources as also observed by Ayoola and Adeyeye (2009). The colour change was observed same in all the drying methods. Ayoola and Adeyeye (2009) observed that the change was due to the loss in the moisture of the groundnut.

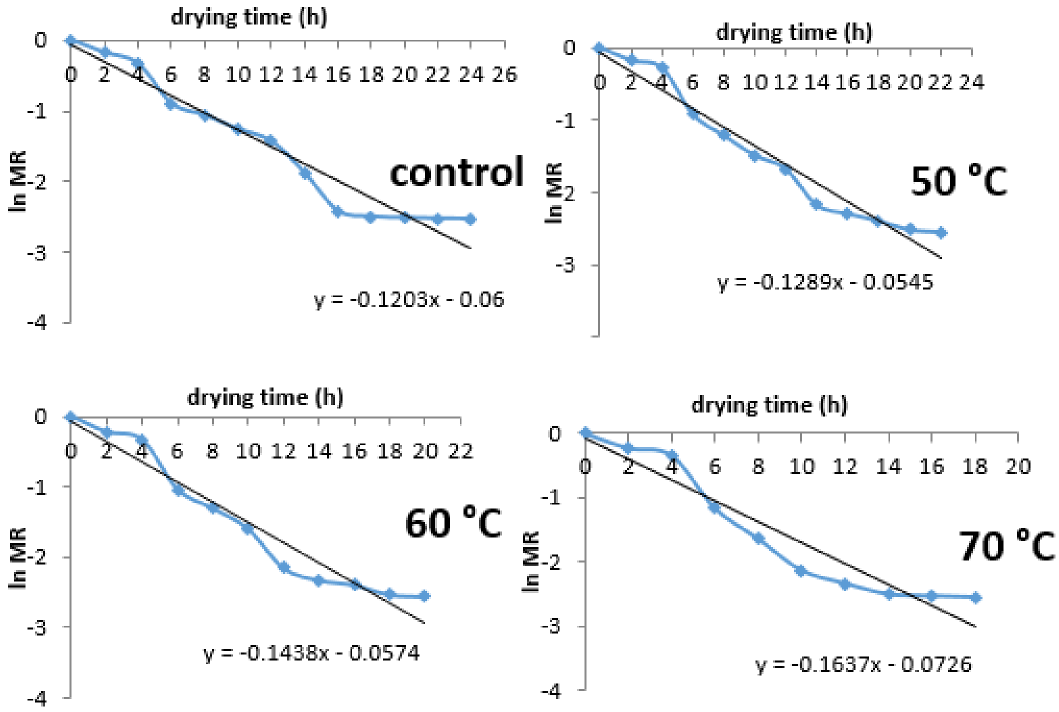

Figure 4 ln MR vs drying time curve

Table 5 Physico-chemical properties of fresh and dried groundnut pods

Sr. No.	Property	Fresh sample	Sun dried	Mechanical dried		
				50 ℃	60 ℃	70 ℃
1.	Moisture content (% db)	124.97±1.34	8.75±0.35	9.41±0.72	9.26±0.73	9.18±1.10
2.	Oil content (%)	41.35±1.67	42.82±0.92	42.99±0.99	43.12±0.82	43.30±1.63
3.	Free fatty acid (%)	19.05±0.49	20.10±0.47	20.21±0.16	20.29±0.76	20.46±0.72
4.	Protein (%)	21.90±0.81	22.99±0.66	23.08±0.33	23.20±0.92	23.42±0.58
5.	Ash content (%)	2.85±0.24	2.89±0.11	2.90±0.18	2.95±0.21	3.06±0.21
6.	Colour change	---	4.76±0.87	4.87±0.99	4.61±1.01	4.83±0.95

*Note: Data is given as mean ±standard deviation

4 Conclusion

The drying of groundnut pods was faster while using mechanical drying at 70ºC with minimum drying time among all the methods. The increase in the drying temperature led to a decrease in the drying time showing that the curves were greatly affected by the drying temperature. The drying process was affected by the movement of moisture from center to surface which caused the drying to happen in the falling rate period. The oil content, free fatty acids and protein content were increased after the drying of groundnut pods as moisture content reduced. According to the statistical analysis applied to five thin layer drying models, the page model was found to be the most suitable model for describing the effect of thin layer drying characteristics of groundnut. The value of effective moisture diffusivity was found to increase with an increase in the drying temperature ranging from 5.5214×10^{-10} to 7.1517×10^{-10} m^2s^{-1}.

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Ethical statements

Conflict of Interest: The authors declare that they do not have any conflict of interest.

Ethical Review: This study does not involve any human or animal testing.

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