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Research Article

Thin Layer Drying Behavior of Spring Groundnut

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ABSTRACT

The aim of present investigation was to study the influence of drying method on the drying behavior of groundnut (*Arachishypogaea L.*), and the acceptability of drying models to predict the drying pattern of groundnut. The groundnut pods of spring TG37A variety was dried using forced circulation solar hybrid dryer and conventional sun drying method. Five mathematical models were fitted to the experimental data to predict the drying kinetics and determine the moisture diffusivity. It was observed from the study that the drying time varied between 20 to 24 hours and logarithmic model was most suitable for representing the effect of thin-layer drying characteristics of groundnut. Effective moisture diffusivity showed a slight difference between mechanical method and open sun dried method. The value is little more for mechanical method because of the higher drying temperature in mechanical drier.

Keywords: Drying kinetics; Drying methods; Mathematical modeling; Moisture diffusivity; Groundnut

INTRODUCTION

Groundnut (*Arachishypogaea L.*) is a species in the legume or "bean" family, known by many other local names such as earthnuts, ground nuts, goober peas, monkey nuts, pygmy nuts and peanuts. Groundnut is the third most important legume crop of world. Groundnut is a significant oilseed, ideal for cultivation in tropic regions of the country World production of groundnut reached a record of about 21 million tons [1]. The most important groundnut producing countries in the world are India, China, USA, West Africa, Sudan, and Nigeria. India ranks first in the world in area (8.5 million hectares contributes about 40% of the total world's area) and production (8.4 million tonnes contributes about 33% of the total world's production. In India, it is available throughout the year and grown mostly under rain-fed conditions. In India, Uttar Pradesh, Madhya Pradesh, Rajasthan, Gujarat, Maharashtra, Karnataka, Andhra Pradesh and Tamil Nadu are major groundnut growing states. In Punjab total area under groundnut crop is 3000 hectare per year and total production of groundnut is 2300 metric ton [2,3].

Groundnut is rich source of protein. It contains about 44%-52% oil and 20% protein. The kernels are consumed either roasted or fried and salted. Its kernel as a whole is highly digestible. The biological value of the groundnut protein is among the highest of the vegetable protein and equals that of casein. Groundnut oil is famous for use in human diet and Gujarati peoples like it more in preparation of their foods as compared to other edible oils. Groundnut oil is primarily used in the manufacturing of vegetable ghee. They are a rich source of thiamin, riboflavin, nicotinic acid and vitamin E. The oil content of the seed varies from 44%-52%, depending on the varieties and agronomic conditions.Groundnut oil finds extensive use as a cooking medium as refined oil. It is also used in soap making, and - cosmetics and lubricants, olefin stearin and their salts. They are rich in protein and vitamins A, B and some members of B2 group. Their calorific value is 275 per 100 gm [2,3].

Various factors such as surrounding atmosphere conditions including temperature and relative humidity, composition of raw materials, type of storage structure and moisture content of crop have a vital effect on storability of agricultural produce. Traditional methods for storage of groundnut include storing in earthen mud bins, bamboo baskets and wicker baskets plastered with mud or cow dung. Such method of storing makes groundnuts prone to fungi and dampness. Groundnuts are semi-perishable and are subject to quality losses during storage through insect and rodent infestation, fungal development, flavour changes, rancidity, viability loss, physical changes like shrinkage and weight loss due to high moisture content. But in normal storage, if the moisture is not properly checked and results in micro toxins in the groundnut resulting in reduction of quality with time [4].

In India, groundnut crop sown during January-February and harvested during May-June as summer groundnut and sown during October-November and harvested in harvested in March-April. At the time of digging, the groundnut pods contain about 40%-

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50% moisture which should be reduced to safe storage moisture content (8%-10%) as rapidly as possible. If groundnut is not dried quickly to this moisture content, then it may be infested by two closely related fungal species *Aspergillus Flavus* and *A. Parasiticus*. Both species produce highly toxic mycotoxins known as aflatoxins. Aflatoxins are carcinogens that can cause liver cancer. Groundnut could be dried either normal sun drying, method developed by Directorate of Oil seed Research (DOR). If the groundnut is harvested in October-November, when the weather is cold, and it is not possible to dry it to a safe storage moisture level by sun drying. Hence, heated air drying is required to reduce its moisture to a safe level before storage to avoid risk of aflatoxins.

Traditionally groundnut is cultivated during kharif season. In winter season almost whole of the groundnut produced in the state is consumed as roasted groundnut. But, with the advent of the high yielding and short duration varieties of spring groundnut, such as TG37A, groundnut is emerged as highly promising third crop in the yearly crop cycle. The crop was harvested in the months of July and August and often stored under high temperature and high relative humidity conditions. The majority of groundnut crop is produced by smallholder farmers. Protecting harvested crop during storage is challenging task for farmers, because insect infestation, fungal growth, oxidation, rancidity and aflatoxin contamination can cause loss of crop. Also, due to high moisture content of crop during harvesting and improper handling and storage practices during rainy season there is buildup of moisture during storage leads to damage of crop due to mycotoxins. There is very less published information available on the drying characteristics of groundnut pods, in order to design a groundnut crop dryer, it is necessary to model the process of drying and develop mathematical relations. Keeping in view the above factors, the present study was planned to investigate the effect of drying method on thin layer drying kinetics of groundnut pods.

MATERIALS AND METHODS

Silver nano particle

The groundnut kernels of TG37A spring variety was procured from Punjab Agricultural University farm. The clean and healthy pods were selected for the study. The initial moisture content of groundnut pods will be determined by standard method till the constant weight was attained [5].

Drying of groundnut pods

The groundnut sample was dried using forced air circulation solar drier and in an open sun drying method. The samples were spread uniformly in the trays and the thickness of the layer was kept between 1.5 cm and 2 cm for both methods. The ambient air temperature was determined using mercury thermometer and relative humidity of ambient air was determined using thermo- hygrometer (0%-100%) for all the samples at regular interval of time. A forced air circulation hybrid convective air solar dryer was operated at average temperature of 60°C in the present study. During the sunshine hours dryer was operated as solar dryer and after that it was connected to the power source. The constant weight of sample was kept in trays of forced circulation solar drier. The moisture loss of groundnut pods was recorded after every 2 hours using digital weighing balance, until the desired moisture content was achieved. A digital temperature and humidity indicator was attached with the thermocouples and the temperature and humidity was displayed on the control panel and recorded at regular interval of time. The drying experiments were repeated twice for all the experimental conditions.

Modeling of thin air convective drying

The drying models used to describe the drying kinetics of sample are shown in (Table 1). Drying parameters like moisture ratio and drying rate were evaluated and Drying curves were plotted to the data for studying the drying characteristics of groundnut. All the moisture and moisture ratio values used were calculated on dry basis. However, Moisture Ratio (MR) was simplified to M/Mo instead of (M-Me/MO-Me) as used by any authors. The Moisture Ratio (MR) was calculated using the following equation 1 [6,7].

$$MR = \frac{M}{M_{o}} \qquad (1)$$

Where, M is the moisture content at any time, Mo is initial moisture content.

The drying rate was also calculated by decrease in moisture content (dry basis) by unit time in minutes.

$$DR = \frac{Mt - M(t+1)}{dt(\text{mins})}$$

Where, Mt is the moisture content at time t, M (t+1) is the moisture content at time t+1, dt is change in time in minutes.

For the five thin layer drying models R_2, SSE and RMSE were the statistical parameters determined to check the fitting. The value of the R_2 should be more than 0.95% for goodness of fit. The higher R_2 values and lower SSE and RMSE values are goodness of fit. Regression analysis was conducted to fit mathematical models by SPSS version 11.5. Similar work has been done on groundnut [8,9].

Table1. List of the 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=aExp(-kt)	Sawhney et al. (1999)
4	Logarithmic	MR=aExp(-kt)$^{+b}$	Akpinar et al. (2006)
5	Wang and Singh	MR=1+at+bt^{2}	Wang and Singh (1978)

Determination of effective moisture diffusivity

In biological materials drying, effective moisture diffusivity is a significant transport property. The dehydrating ability of material is given by effective moisture diffusivity. During drying, it can be assumed that diffusivity, explained with Fick's diffusion equation, is the only physical mechanism to transfer the water to surface. Effective moisture diffusivity, which is affected by composition, moisture content, temperature and porosity of the material, is used due to the limited information on the mechanism of moisture movement during drying and complexity of the process. It was considered that groundnut has constant moisture diffusivity;

groundnut has infinite cylindrical geometry and uniform initial moisture content, no external resistance to moisture, no shrinkage in the product during drying and negligible external and internal heat transfer effect [10-13].

$$MR = \frac{M - Me}{M - Me} - \frac{4}{\pi 2} \sum_{n=0}^{1} 1/(2n+1)^2 \frac{\exp(-(2n+1)2\pi 2 D_{eff} t)}{4l2} \qquad (2)$$

Where 4π/2 is shape factor for cylindrical geometry

D_{eff}=Effective diffusivity ($m^2 s^{-1}$)

L=Characteristic length, thickness (m)

n=Positive integer

When drying is done for long duration n=1, equation (3) can be simplified to equation (4) by applying log.

$$InMR = In\frac{4}{\pi 2} - \pi^2 D_{eff} t / 4l^2 \qquad (3)$$

By plotting ln (MR) versus time gives k as slope:

$$k = \frac{\pi^2 D_{eff} t}{4l^2} \qquad (4)$$

Statistical analysis

The experimental data was recorded at regular intervals for all the drying samples and the recorded data was fitted into drying curves. The drying curves were fitted into five thin layer drying models and their goodness of fit was determined using some statistical parameters. There parameters included coefficient of determination (R_2), Sum Square Error (SSE) and Root Mean Square (RMSE). Regression analysis was conducted to fit mathematical models by SPSS version 11.5.

$$SSE = \frac{\sqrt{\sum}(MRT - M\,\mathrm{Re})2}{n-2}$$

$$RMSE = \frac{\sqrt{\sum}(MRT - M\,\mathrm{Re})2}{n}$$

Where, MRt=Theoretical drying ratio, MRe=Experimental drying ratio, N=Number of observations

The value of R_2 should be higher and the values of SSE and RMSE should be lower for goodness of it [9].

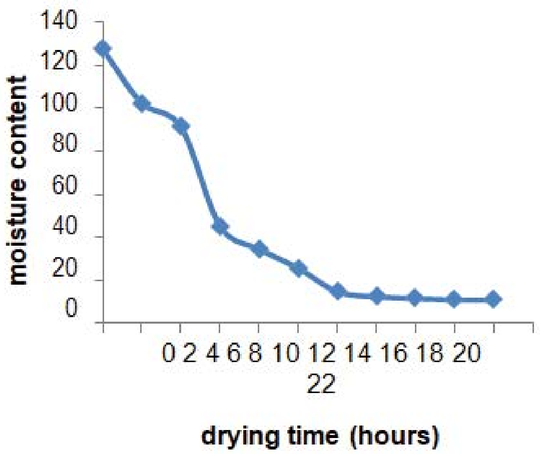
RESULT AND DISCUSSION

Drying characteristics of groundnut pods

The groundnut pods were dried using natural sun drying method and using forced air circulation hybrid convective air solar dryer. The initial moisture content of the sample was around 122% ± 4% dry bases. The sample was dried to moisture of 9% ± 1% dry basis. There was significant impact of the drying method on the drying characteristics of the groundnut. The drying characteristics of the groundnut pods are given in figures below. As the drying time increased there was continuous decrease in the moisture content and on maintaining a continuous drying temperature there was decrease in the drying time. The shortest and the longest drying times were recorded as 20 hours (for mechanically dried sample) and 24 hours (for sundried sample) as shown in (Figure 1).

The changing trends of moisture profile in pods with drying time due to the effect of drying methods are presented in terms of moisture ratio versus drying time as shown in (Figure 2). From the figures, it is seen that moisture ratio decreased with increasing time. During the initial hours of drying the loss in moisture ratio was considerably fast as compared to later hours of drying. Drying using forced air circulation hybrid convective air solar dryer showed rapid decrease in moisture ratio as compared to the sun drying. As per some previous studies it was found that drying temperature is main factor that controls the drying characteristics. So, temperature was non-uniform and kept on changing in sun drying method, the following trends were seen in moisture ratio.

The graph between the drying rate and drying time were given below in (Figure 3) for mechanical drying method and sun drying method. For both the samples, the drying rate increased initially and then decreased after some hours. The drying rate was highest after 6 hours of drying in both the cases. This was because loss of moisture was from the surface during those hours. The maximum drying rate for mechanical drying method and sun drying method was 0.385°C and 0.229°C respectively. The final decreasing trend was observed after 12 hours in mechanical drying method and 15



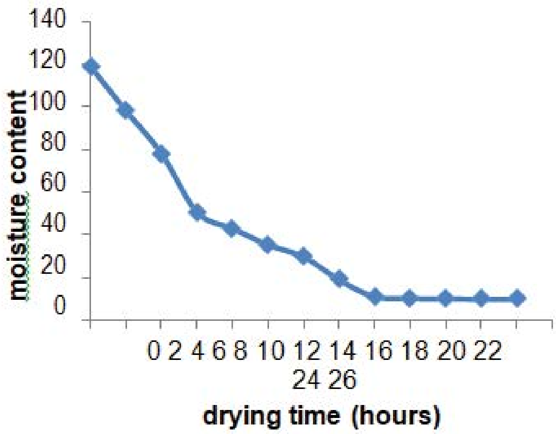


Figure 1: Effect of drying methods on moisture content of groundnut samples.

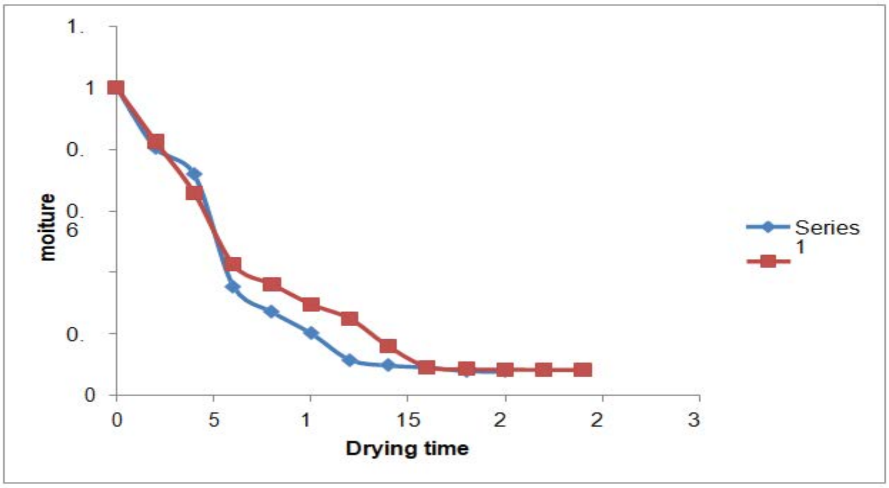


Figure 2: Effect of drying methods on moisture ratio of groundnut samples.

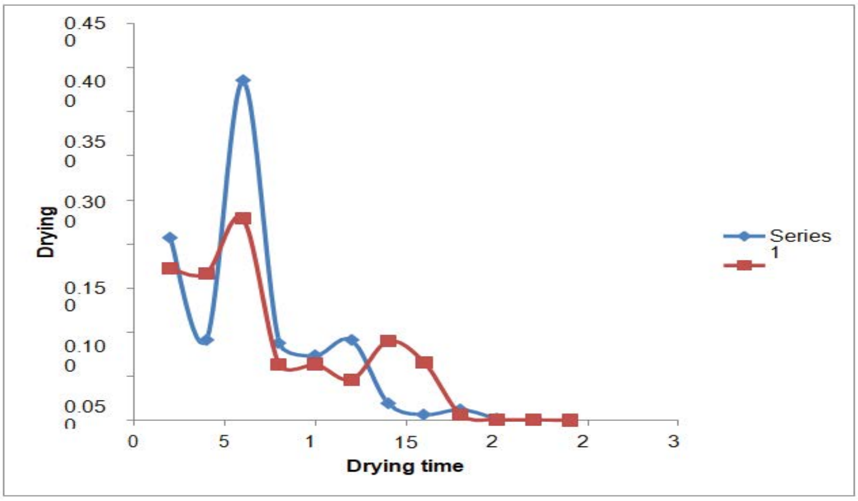


Figure 3: Effect of drying methods on drying rate of groundnut samples.

Table 2: Model parameters for the groundnut.

Drying method	Model No.	Model expression	Model parameters				Goodness of fit		
			a	k	b	n	R_2	SSE	RMSE
Mechanical	1	MR=Exp(-kt)	-	0.146		-	0.9326	0.06725	0.06083
	2	MR=Exp(-kt^n)	-	7.44		0.811	0.9505	0.40107	0.36278
	3	MR=aExp (-kt)	0.925	0.14		-	0.9346	1.37437	1.24316
	4	MR=aExp(-k t)+	1.063	0.149	-0.013	-	0.977	0.003308	0.0455
	5	MR=1+at+b t^2	-0.115	-	0.004	-	0.977	0.010532	0.10262
Open sun	1	MR=Exp(-kt)	-	0.127	-	-	0.9692	0.03292	0.03005
	2	MR=Exp(-kt^n)	-	8.3	-	0.8943	0.9832	0.40365	0.36848
	3	MR=aExp(-kt)	0.9979	0.126	-	-	0.9692	0.03295	0.03008
	4	MR=aExp(-kt) +b	1.1017	0.131	0.01	-	0.971	0.00417	0.05417
	5	MR=1+at+bt^2	-0.096	-	0.002	-	0.989	0.01721	0.1312

hours in sun drying method. This was due to temperature variation in both the drying methods [14].

Evaluation of the drying models

The drying data obtained from experiments were fitted into selected five drying models for different drying methods. The coefficients and the drying constants of the five selected thin layer drying models are given in (Table 2). For the five thin layers drying models R_2, SSE and RMSE were the statistical parameters determined to check the fitting. The statistical analysis values are also summarised in (Table 2). The value of the R_2 should be more than 0.95 for goodness of fit [8].

In most of the cases the R_2 values were more than 0.95 indicating good fit with some exception showing errors. The values of the R_2 varied between 0.9326 and 0.991, this shows that most of the models predicted the thin layer drying process with some exceptions with errors. Logarithmic model gave higher R_2 and lower SSE and RMSE. Thus, the thin layer drying characteristics could be represented by the Logarithmic model, which suggested mechanical drying of groundnut. Regression analysis was conducted to fit mathematical models by SPSS version 11.5.

$$\mathrm{MR}= 0.1017 Exp\left(-0.131\ \mathrm{xt}\right)+0.01$$

Determination of effective moisture diffusivity

The effective diffusivity of the food material characterizes its intrinsic mass transport property of moisture which includes molecular diffusion, liquid diffusion, vapour diffusion, hydrodynamic flow and other possible mass transfer mechanics. The values of effective moisture diffusivity obtained from this study lies within the general range from 10 m^2/s-11 m^2/s to 10 m^2/s-09 m^2/s for food materials.

From Table 3, it can be seen that there is a slight difference between the values of D_{eff} for mechanical method and open sun dried method. The value is little more for mechanical method because of the higher drying temperature in mechanical drier. At higher temperature the heating energy increased the activity of water molecules and vapour pressure inside the sample leading to higher moisture diffusivity. Similar results were reported by Akoy [7].

Table 3: Model parameters for the groundnut.

Drying method T(°C)	k	D_{eff} (m^2/s)
Mechanical drying 60°C	-0.1375	1.28707E-10
Open sun drying (35-45)°C	-0.1174	1.16067E-10

CONCLUSION

In most of the cases the R_2 values were more than 0.95 indicating good fit. The values of the R_2 varied between 0.9326 and 0.991, this shows that most of the models predicted the thin layer drying process with some exceptions with errors. Logarithmic model gave higher R_2 and lower SSE and RMSE. Thus, the thin layer drying characteristics could be represented by the Logarithmic model, which suggested mechanical drying of groundnut. It was seen that there is a slight difference between the values of Deff for mechanical method and open sun dried method. The value is little more for mechanical method because of the higher drying temperature in mechanical drier.

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