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DRYING KINETICS OF GINGER RHIZOME (*Zingiber officinale*)

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Abstract

This paper presents the drying kinetics of ginger rhizome under blanched and nonblanched conditions using hybrid solar dryer and mechanical tray dryer at three temperature levels. The drying rate increases with the increase in drying air temperature and blanching also increases the drying rate. The drying rate depends on shape and size of the ginger rhizomes. The highest drying rate was found for sliced samples of ginger rhizome followed by splitted and whole root samples. Five thin layer drying models were fitted to the experimental data of blanched and sliced ginger rhizomes. The Page equation was found to be the best to predict the moisture content of sliced ginger rhizome in thin layer. The agreement between the predicted and experimental results was excellent. Colour of ginger rhizomes was slightly changed after drying. Lightness of ginger rhizomes decreased with an increase in drying temperature for all samples except sliced and blanched samples. For drying of ginger rhizome, it should be sliced and blanched and dried below 70 ^{0}C for better quality dried products.

Keywords: Ginger rhizome, hybrid solar dryer, tray dryer, blanching, thin layer drying model, colour change.

Introduction

Ginger (*Zingiber officinale*) is a herb in plant habit. Fresh ginger root is usually consumed as spice in the tropical countries and dried ginger is used as medicinal plant internationally. Dried ginger is produced from the mature rhizome. As the rhizome matures, the flavour and aroma become much stronger. Dried ginger can be ground and used directly as a spice or in medicinal use and also for the extraction of ginger oil and ginger oleoresin. Ginger possesses stimulant, aromatic and carminative properties when taken internally and when chewed it acts as a sialagogue. It is of much value in tonic dyspepsia, especially if it is accompanied with much flatulence; and as an adjunct to purgative medicines to correct griping. Quality specifications for export as medicinal herb, it required to be properly cut into pieces, well dried and proper storage.

Drying is the most common and fundamental method for post-harvest preservation of medicinal plants because it is a simple method for the quick

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conservation of the medicinal qualities of the plant material. Quality distinction was made some 4000 years ago in ancient Egypt between medicinal plants dried in the sun and those dried in the shade (Heeger, 1989). However, factors such as scale of production, availability of new technologies and pharmaceutical quality standards must be considered for medicinal plant drying.

Natural drying, i.e., drying without auxiliary energy either in the field or in sheds, should only be considered for drying of small quantities. In cases of mass production, the use of mechanical drying is indispensable. For the preservation of active ingredients of medicinal plant materials, comparatively low drying temperatures are recommended and, as a result, the drying duration is comparably long.

Drying represents 30 to 50% of the total costs in medicinal plant production (Qass and Schiele, 2001) and therefore, it is crucial that factors determining the high costs are identified. Currently, energy demand of drying represents a significant cost factor, especially with the increased price of fossil fuels. This is largely due to the high moisture content of the flowers, leaves or roots to be dried. Moreover, drying performance takes authoritative influence on the quality of the product and, therefore, on its value.

Drying temperature should be chosen as high as possible without reducing the quality of the medicinal plant to achieve increased dryer capacity. Maximum allowable temperatures depend mainly on the chemical composition of the active ingredients of the medicinal plant species under consideration. For glycoside species, a maximum temperature of 100^0C is recommended, for mucilage species 65 ^{0}C and for essential-oil species 35 to 45 ^{0}C (Maltry *et al.*, 1975). For some products drying either in the shade is superior to other methods or solar drying is superior to sun drying in terms of essential oil contents (Ozguven *et al.*, 2007). Numerous types of belt and batch dryers have been frequently used in practice for drying herbal and medicinal plants. Soysal and Öztekin (2001) reported the performance and economic analysis of a heated air tray dryer for drying of *Mentha piperita* and *Hypericum perforatum*.

Several studies have been reported for solar drying of herbal and medicinal plants, such as mint, sage, and hops (Muller *et al.*, 1989), aonla (Haque and Bala, 1996) and rosella flower (Janjaia, 2008). Solar drying results in considerable reduction in drying time and production of quality dried products.

Arabhosseini (2005) fitted a number of thin layer drying equations to the experimental data of tarragon leaves as well as chopped plants and the Page equation was selected. Müller (2007) compiled experimental studies in terms of models for drying kinetics and losses of active ingredients during drying at different drying conditions.

The effects of solar drying on the appearance, aroma/flavour, pungency and the ginger oil/oleoresin yield of dried ginger and analysis of the ginger oil/oleoresin contents are essential for processing of ginger. Therefore, a suitable method of drying and storage of powder of *ginger* rhizome tubers is needed (Yiljep *et al.*, 2005). Although several studies have been reported on drying of herbs and medicinal plants (Soysal and Öztekin, 2001; Janjaia *et al.*, 2008; Arabhosseini, 2005; Yahya *et al.*, 2004; Müller, 2007; Böhm *et al.*, 2002; Heindl and Müller, 2002; Heindl, 2005; Arabhosseini *et al.*, 2007) no study has been reported on drying of ginger rhizome. The purpose of this study is to determine the drying kinetics of ginger rhizome using solar hybrid and tray dryer; to determine the optimum drying air temperature, develop models of drying kinetics and also assess the quality attributes of dried ginger rhizome in terms of colour.

Materials and Method

The hybrid dryer installed at Bangladesh Agricultural Research Institute (BARI) was used for drying of ginger rhizome at 50 ^{0}C (Hossain and Hoque, 2008) and the tray dryer at BARI laboratory was used for drying of ginger rhizome at 60 ^{0}C and 70 ^{0}C and three drying experiments were conducted. Fresh ginger rhizomes were collected from local market of Gazipur district in Bangladesh. The ginger rhizomes were processed in three different sizes e.g., whole (60 mm length @ 20 mm dia. finger), splitted (60 mm length @ 20 mm dia finger splitted longitudinally to make two) and sliced (20 mm dia. finger @ 4 mm thickness) . Three samples of 100 g each of the different shape and size of the product were water blanched and another three samples were not blanched.

Fresh ginger rhizomes were dried in three forms- whole, longitudinally splitted, and sliced. Whole fresh rhizomes were cut longitudinally to make equal two parts by knives. Slicing was done with a mechanical slicer in 4 mm in thickness. Three samples of all three forms were blanched at 80 ^{0}C for 5 minutes (Murad et al., 2004). The initial moisture content of the ginger rhizome was determined by oven method drying at 105 ^{0} C for 24 hours (Park *et al.*, 2002).

Comparison of temperature at 50, 60, and 70 ^{0}C were made in this study. Here temperature is factor and there is no effect of method of temperature (whether it is raised by solar, cabinet dryer or other means). It is convenient to raise temperature 50 ^{0}C in solar dryer and 60 and 70 ^{0}C temperature in cabinet dryer. So, solar and cabinet dryer was used to dry ginger at different temperature.

Description of the hybrid solar dryer

The dryer basically consists of a solar collector and a drying unit. A schematic view of the solar dryer is shown in Fig. 1. The dimensions of the flat plate concentrating solar collector were 2.3 m long, 1.6 m wide, and 0.5 m high. The transparent cover of the collector was 4 mm thick clear glass. Black painted corrugated iron sheet about 200 mm below the glass cover was used as an absorber plate. To increase the efficiency of the solar collector, flat type reflector made of glass mirror was added at top of the solar collector. The dimensions of the reflector were the same as those of the solar collector so that it could be used as a reflector in day time and as a cover in night time or in adverse weather. This reflector had adjustable angles that could be changed according to the change of the sun's angle during the day to collect higher amount of sun rays that fall down on the solar collector. In addition, the collector was placed on 4 legs with 140 mm wheel to turn the solar collector horizontally and change its direction according to the change of the sun's angle. The solar collector was insulated by 50 mm thick polystyrene. A centrifugal blower operated by a 0.75 kW, 220 V electric motor was connected at one side of the collector to draw the atmospheric air in the collector and push out the heated air into the dryer at a desired air velocity. Air flow was controlled by a variac connected with the electric motor. For auxiliary heating, two electric heaters (2 kW x 2= 4 kW) were installed at the entry of the collector. A temperature controller was set to maintain constant temperature inside the dryer.

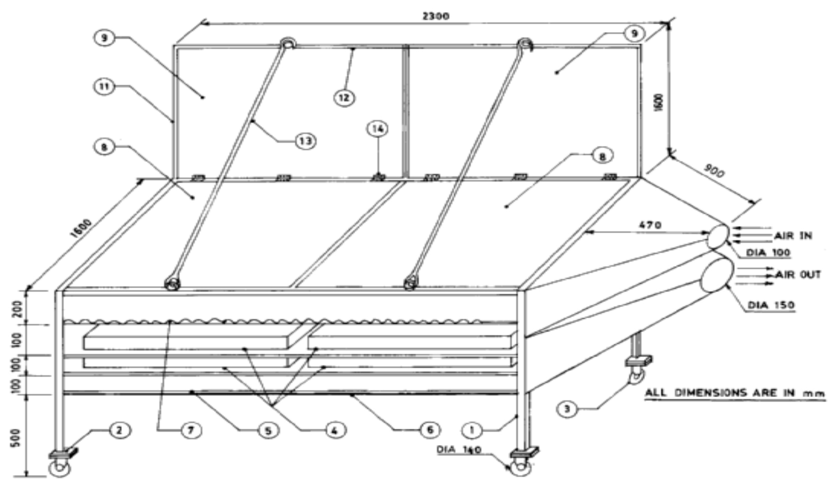


Fig. 1. Schematic view of a solar hybrid dryer: (1) Leg , (2) base plate, (3) wheel, (4) tray, (5) floor, (6) insulation, (7) absorber plate, (8) glass cover, (9) reflector, (11and 12) reflector frame, (13) reflector adjusting support and (14) hinge.

The length and width of the solar dryer were same as the collector (2.30 m ×1.60 m). It was located directly under the solar collector and 200 mm under the absorber plate. It was divided into 4 parts with equal dimensions. In each of the parts, there were 2 trays for drying. This allows the usage of 8 drying trays in the drying unit. The drying air was passed across the asparagus placed in thin layers on 8 horizontally stacked trays and arranged in two vertical columns. Each tray was made of wooden frame and plastic net with dimensions of 1040 mm × 780 mm. The drying air was heated up in the solar collector and passed to the drying chamber. The drying air from the solar collector was passed through a curved passage downward, then again turned into the drying unit to flow over and under all the drying trays and then exhausted through an outlet.

Description of the mechanical tray dryer

The mechanical tray dryer consists of a drying chamber, heater, electric blower etc. The overall dimensions of the drying chamber of the mechanical tray dryer are 1.42 m × 0.64 m × 0.86 m. Inner dimensions of the chamber are 0.80 m × 0.50 m × 0.60 m. There were arrangements for fixing five trays. Heated air was passed in over the trays through fourteen holes and passed out with same numbers of holes. Air was circulated over the electric heater installed on the bottom of the dryer with a fan sucking fresh air from the right side of the dryer. There was an arrangement to control the velocity of the air by reducing or increasing the opening of the holes. Sensors were used to detect the temperature level. When the temperature is higher than the desired temperature, the heating system is off and the reverse is true when the temperature is below the desired temperature.

Experimental procedure

The ginger rhizome as a whole, splitted, and sliced (4 mm) were dried under blanched and non-blanched conditions at 50 ^{0}C using solar hybrid dryer and at 60 ^{0}C and 70 ^{0}C using tray dryer. Before starting an experimental run, the whole apparatus was operated for at least one hour to stabilize the air temperature and air velocity in the dryer. Drying was started usually at 09:00 am and continued until it reached the final moisture content (about 8 to 9%, wb). Ambient temperature and temperature inside the dryer temperature was measured with a digital thermometer (K202, Voltcraft digital thermometer, Germany) connected with k type thermocouples. Solar radiation was measured with a Lux meter (LX-9626, China) during the day time**.** Velocity of drying air was measured with a thermo-anemometer (AM-3848, China). Weight losses of the samples in the solar dryer were recorded during the drying period at two hours of interval with an electronic balance (EK-200g, Max 200 ± 0.01g). After completion of drying, the dried samples were collected, cooled in a desiccator to the ambient temperature and then sealed it in the plastic bags.

Colour measurement

The colour of fresh and dried ginger rhizome samples were measured by a chromameter (CR-400, Minolta Co. Ltd., Japan) in CIE (Commission

Internationale l'Eclairage) Lab chromaticity coordinates. L^*, a^* and b^* represent black to white (0 to100), green to red (-ve* to +ve) and from blue to yellow (-ve to +ve) colours, respectively. Out of five available colour systems, the $L^*a^*b^*$ (Krokida et al., 1998; Lozano and Ibarz, 1997 and Maskan, 2001) and $L^*C^*h^*$ (Zhang et al., 2003) systems were selected because these are the most used systems for evaluation of the colour of dried food materials. The instrument was standardized each time with a white ceramic plate. Three readings were taken at each place on the surface of root samples and then the mean values of L^*, a^* and b^* were averaged. The different colour parameters were calculated using the following equations (Camelo and Gomez, 2004).

Hue angle indicating colour combination is defined as:

$$\text{Hue angle} = \tan^{-1}(b^*/a^*) \text{ (when } a^*>0) \quad (1)$$

$$\text{Hue angle} = 180^0 + \tan\text{-}1(b^*/a^*) \text{ (when } a^*<0) \quad (2)$$

and Chroma indicating colour saturation is defined as:

$$\text{Chroma} = (a^{*2}+b^{*2})^{1/2} \quad (3)$$

Thin layer drying equations

Thin layer drying equations and expressions for the drying parameters as a function of drying conditions are required for simulation of the drying systems (Bala, 1997). Three general approaches for thin layer drying are the development of (1) empirical equations, (2) theoretical equations, and (3) semi-theoretical equations. Theoretical approach concerns either the diffusion equation or simultaneous heat and mass transfer equations. Semi-theoretical approach concerns approximated theoretical equations. The main justification of the empirical approach is a satisfactory fit to all experimental data. The details of the development of thin layer drying models and expressions of the drying parameters are given in Bala (1997). This study considers empirical and semi-theoretical thin layer equations.

Mathematical models for thin-layer drying of sliced asparagus root under blanched conditions were developed by using direct least square method between moisture ratio (*MR*) and drying time (*t*). Moisture ratio was defined as follows:

$$MR = \frac{M_t - M_e}{M_0 - M_e} \quad (4)$$

*M*e values were obtained from drying curves and were set equal to moisture content at which sample weight became constant with drying time. Five commonly used thin layer equations were selected to fit the experimental data of drying of sliced ginger rhizome by the direct least square method using SPSS

11.5 and these are shown in Table 1. The constant final moisture contents were considered as the equilibrium moisture contents of the samples.

The equations were evaluated in terms of coefficients of determination (R^2) and root mean square errors (RMSE) and these are defined as:

$$R^2 = \frac{\left(\sum M_{exp} M_{pred}\right)^2}{\sum M_{exp}{}^2 \sum M_{pred}{}^2} \tag{5}$$

$$RMSE = \sqrt{\sum_{1}^{N} \left(\frac{M_{pred} - M_{exp}}{df} \right)^2} \tag{6}$$

Residuals of each model were plotted with experimental moisture contents. If residual plots indicate a systematic pattern, there is a systematic error in model prediction (Chen and Morey, 1989; Kaleemullah and Kailappan, 2004). A model was considered to be the best when the residual plots indicated uniformly scattered points i.e. random; RMSE is a minimum value and R^2 is a maximum value (close to 1.0).

Table 1. Thin layer drying models.

Serial No.	Name of model	Model expression
1	Newton Equation	$\frac{M_t - M_e}{M_0 - M_e} = \exp(-kt)$
2	Henderson and Pabis	$\frac{M_t - M_e}{M_0 - M_e} = a\exp(-kt)$
3	Page Equation	$\frac{M_t - M_e}{M_0 - M_e} = \exp(-kt^n)$
4	Approximation of Diffusion Equation	$\frac{M_t - M_e}{M_0 - M_e} = a\exp(-kt) + (1-a)\exp(-kbt)$
5	Midilli et al. (2002) Equation	$\frac{M_t - M_e}{M_0 - M_e} = a\exp(-kt^n) + bt$

Results and Discussions

Effect of drying

The effect of temperature for different shapes and sizes of ginger rhizomes on drying characteristics under blanched and non-blanched conditions are shown in Fig. 2 and Fig. 3, respectively.

Drying rate of whole ginger rhizomes under blanched and non-blanched conditions was extremely low and the desired moisture contents were reduced from initial moisture content 87.98% and 84.97% (wb) to the moisture content 75.73% and 68.70% (wb) under blanched condition and to the moisture content 81.98% (wb) and 77.46% (wb) under non-blanched condition after 20 hours of drying at 50 and 60 ^{0}C, respectively. Though drying rate was, relatively, high at 70 ^{0}C, still the moisture content reduction were about 40.18% and 59.85% (wb) after 20 h of drying under blanched and non-blanched conditions.

The drying rate of splitted ginger rhizomes increased with the drying air temperature, but the rate of increase of drying rate was relatively low at 50 ^{0}C. Blanched splitted ginger rhizomes were dried at 70 ^{0}C in a mechanical dryer from 85.76% (wb) to a moisture content of 9.11% (wb) in 20 hours, while at 60 ^{0}C, it took about 32 h to obtain a moisture content of 11.32% from the initial moisture content of 84.97% (wb). Non-blanched splitted ginger rhizomes were dried at 70 ^{0}C in a mechanical dryer from 85.76% (wb) to a moisture content of 13.44% (wb) in 20 hours while at 60 ^{0}C it took about 32 hours to obtain a moisture content of 13.65% from the initial moisture content of 84.97% (wb). Splitted ginger rhizomes were dried from the initial moisture content of 87.98% (wb) to 22.54% and 32.96% (wb) under blanched and non-blanched conditions in 32 hours of drying at 50 ^{0}C. This implies that drying rate of splitted ginger rhizome increases with the increase of drying temperature.

Sliced ginger rhizomes were dried from an initial moisture content of 85.76% (wb) to moisture content of 7.41% and 8.73% (wb) under blanched and non-blanched conditions in 16 and 18 hours, respectively, at 70 ^{0}C in mechanical tray dryer, while at 60 ^{0}C, sliced ginger rhizomes were dried from an initial moisture content of 84.97% (wb) to moisture content of 8.21% (wb) and 8.59% (wb) under blanched and non-blanched conditions in 20 and 24 hours. But sliced ginger rhizomes were dried from an initial moisture content of 87.98% (wb) to moisture content of 10.27% and 14.62% (wb) under blanched and non-blanched conditions in 26 and 28 hours at 50 ^{0}C. This implies that the drying rate increases with the increase of temperature from 50 ^{0}C to 60 ^{0}C, but the drying rate is almost same for drying either at 60 ^{0}C or 70 ^{0}C and it is much more prominent under blanched conditions. Ginger rhizomes should be dried to about 8% (wb) of moisture content so that samples can be powdered and for this reason ginger rhizomes should be dried in the sliced form either at 60 ^{0}C or 70 ^{0}C. Logically mechanical drying or solar assisted drying may be recommended for drying of ginger rhizomes.

The highest drying rate was found for sliced samples followed by splitted and whole rhizome samples. This highest drying rate of the sliced samples might be due to higher diffusion for sliced samples because of its two cut surfaces with small diffusion length to travel towards the cut surfaces. The splitted samples had one cut surface to the drying environment and the other surface was the skin resulting high diffusion length and less area exposed to the environment. Diffusion rate of whole rhizome was very small and drying rate was also extremely low.

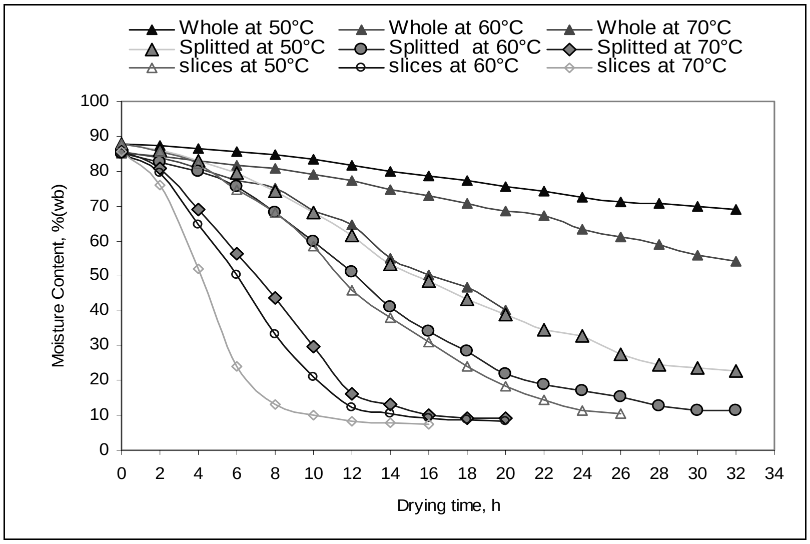


Fig. 2. Effect of temperature for different shape and size of blanched ginger rhizomes

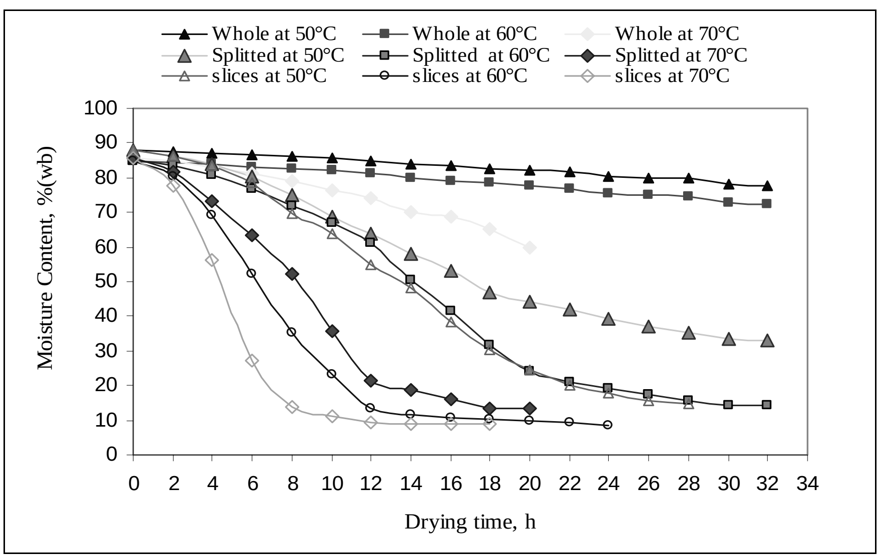


Fig. 3. Effect of temperature for different shape and size of non-blanched ginger rhizome.

The effect of blanching on drying characteristics of ginger samples of different shapes and sizes for temperature levels of 50, 60, and 70 ^{0}C are shown in Fig. 4, Fig. 5, and Fig. 6, respectively. Blanching increases the drying rate (Bala, 1997). There is a significant difference between the drying curves for blanched and non-blanched samples for splitted and sliced ginger rhizomes and this difference becomes a minimum at 70 ^{0}C. This might be due to the fact that during blanching, the samples were partially cooked and some cells or tissues of splitted and sliced ginger rhizome might be disrupted or loosened. As a result, moisture diffusion was higher and hence the drying rate was higher. The effect becomes more prominent with the increase of the temperature. Similar results have been reported by Hossain *et al.* (2007) for red chilli.

However, the moisture content of the whole ginger rhizome remains almost constant during the drying period and this is true for either blanched whole ginger rhizomes samples or non-blanched whole ginger rhizomes samples. This implies that the thick skin of the whole ginger rhizomes prevents the moisture diffusion through the skin.

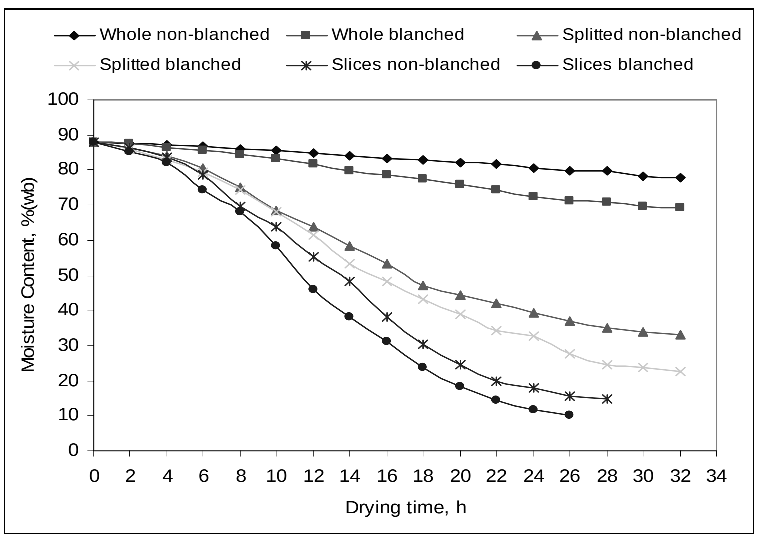


Fig. 4. Effect of blanching on drying for different shape and size of ginger rhizome dried at 50 ^{0}C.

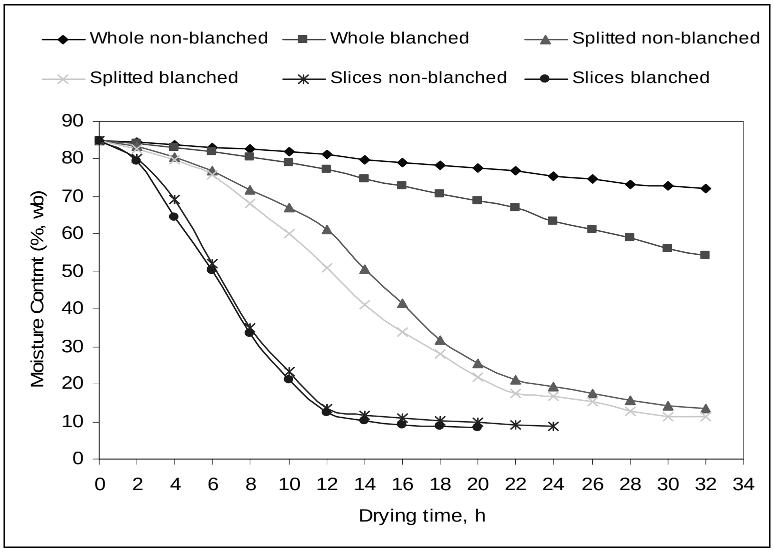


Fig. 5. Effect of blanching on drying for different shape and size of ginger rhizome dried at 60 ^{0}C.

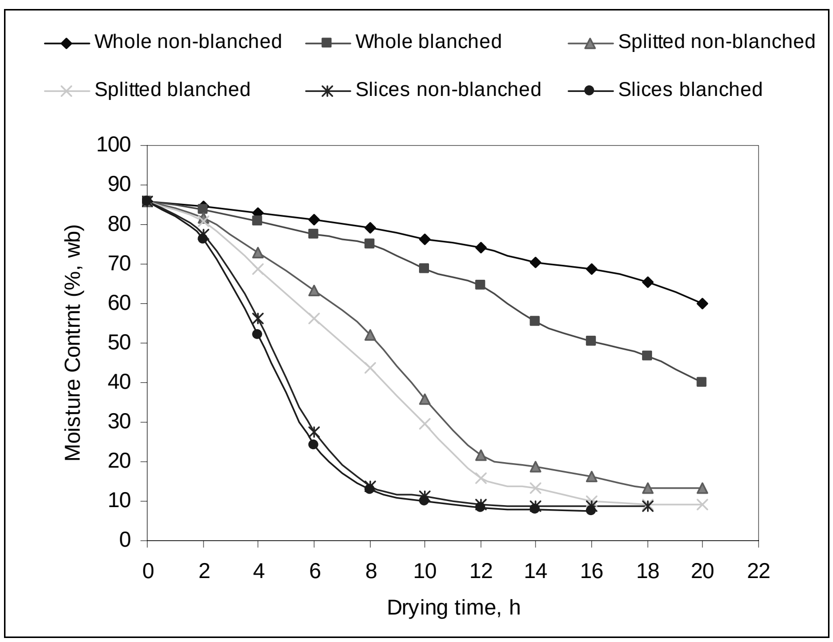


Fig. 6. Effect of blanching on drying for different shape and size of ginger rhizome dried at 70 ^{0}C.

Table 3. Model parameters, coefficient of determination (R^2), root mean standard error (RMSE), grade and ranking of thin layer drying models at different temperatures.

Models	Temp. (°C)	a	b	k	n	R^2	RMSE	Grade Point	Rank
Newton	50			0.159942		0.9874	0.0039		
	60			0.277501		0.9883	0.0018	3.16	4
	70			0.399923		0.9900	0.0036		
Henderson and Pabis	50	1.05370		0.167445		0.9900	0.0596		
	60	1.037016		0.285821		0.9895	0.0430	1.83	5
	70	1.019779		0.405722		0.9904	0.0652		
Page	50			0.087498	1.296297	0.9991	0.0170		
	60			0.160821	1.369787	0.9987	0.0148	4.00	1
	70			0.236738	1.45232	0.9999	0.0041		
Approxim-ation of Diffusion	50	20.3279	1.039328	0.285134		0.9992	0.0179		
	60	37.05262	0.989062	0.183674		0.9920	0.0401	3.33	3
	70	17.96628	1.060838	0.793326		0.9999	0.0046		
Midilli *et al.*(2002)	50	0.99819	5.28E-06	0.086745	1.299746	0.9992	0.0196		
	60	1.004872	3.79E-05	0.163046	1.364374	0.9987	0.0169	3.83	2
	70	1.000421	5.72E-05	0.674964	1.214447	0.9999	0.0035		

Thin layer drying equations

Model parameters, coefficient of determination (R^2), root mean square error (RMSE), grade points and ranking of thin layer drying models at different temperatures are presented in Table 3. From the table, it is observed that based on the highest average coefficient of determination and lowest root mean square error, Page model posses highest grade point and ranked first. Here, the highest R^2 and the lowest RMSE values indicated the highest grade point and lowest rank. The lowest ranked model was considered to be the best fitted model. Hence, Page model ranked one and the Midilli *et al.* (2002) model ranked two followed by the Approximation of diffusion model, Newton model, and Henderson and Pabis model.

Residual plots of different models for single layer drying of ginger rhizome for drying temperature of 50, 60, and 70 ^{0}C are shown in Fig.7. For Page model the residual plots indicated a scattered pattern and the residuals are very close to X-axis leading to suitability for predicting single layer drying of ginger. For other models, the residual plots indicated a systematic pattern and/or the residuals are not close to X-axis.

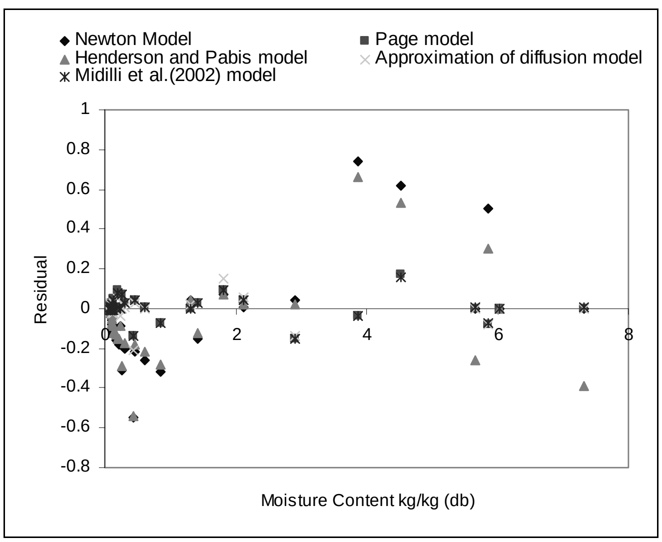


Fig. 7. Residual plots of different models for single layer drying of sliced ginger.

Estimation of different drying parameters

The parameters of Page model at variable temperatures (50^0 to 70 ^{0}C) are found to be a linear function of air temperature. Following regression equations were developed for the parameters of Page model as a function of temperature.

$$k = 0.0075Ta - 0.286 \qquad (R^2 = 0.999) \qquad (7)$$

$$n = 0.0078Ta + 0.9047 \qquad (R^2 = 0.998) \qquad (8)$$

Substituting the values of k and n from the equations (7) and (8) into the Page equation in Table no 1, we get the following equation in terms of temperature

$$M = Me + (Mo - Me)\exp(-(0.0075Ta - 0.286)t^{0.0078Ta+0.9047}) \qquad (9)$$

Fig. 8 shows the comparison between the experimental moisture content and moisture content predicted from the Page model for the drying temperature of 50^0, 60^0 and 70 ^{0}C respectively. The predicted data mainly banded around the straight line which showed the suitability of the model in describing single layer drying behaviour. Furthermore, the predictions are within the acceptable limit (1.70%) (O'Callaghan *et al.*, 1971).

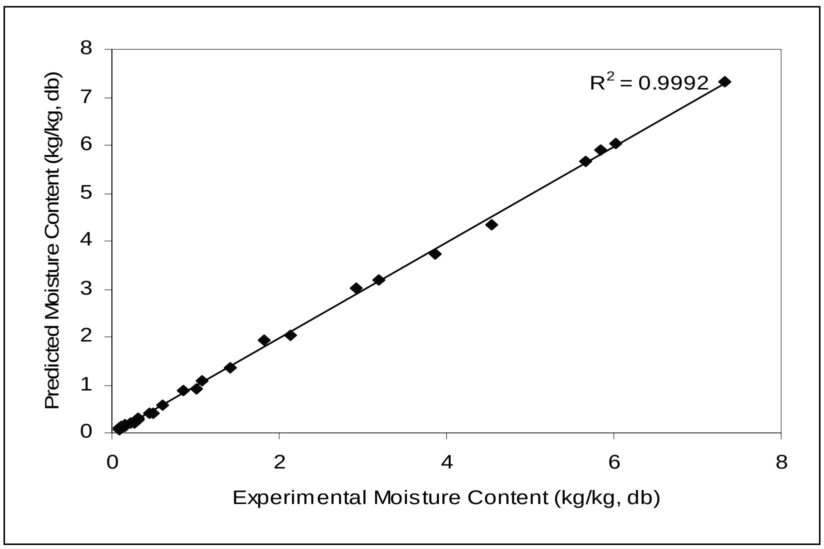
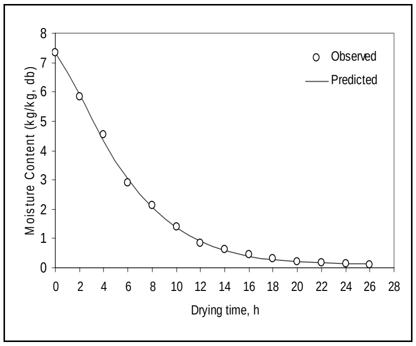


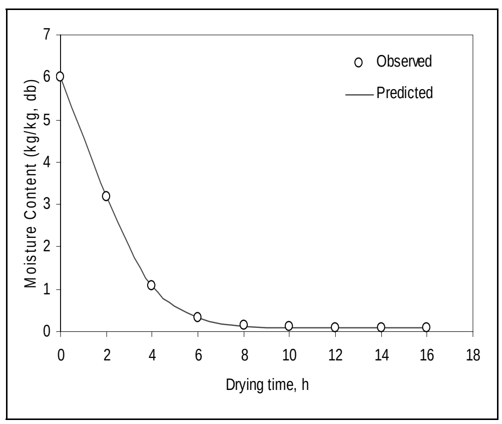
Fig. 8. Experimental and predicted moisture content for single layer drying of ginger rhizome at 50^0, 60^0 and 70 ^{0}C.

Comparison of the experimental data and predicted results from the Page equation for drying of ginger rhizome at 50 ^{0}C, 60 ^{0}C and 70 ^{0}C are shown in Fig. 9(a), Fig 9(b) and Fig 9(c), respectively. The agreement between the predicted and experimental results is excellent.



(a) Dried at 50 ^{0}C

(b) Dried at 60 ^{0}C



(c) Dried at 70 ^{0}C

Fig. 9. Comparison of predicted results of the Page model with the experimental data for dried at (a) 50 ^{0}C, (b) 60 ^{0}C and (c) 70 ^{0}C.

Colour degradation

The colour of ginger rhizomes were measured before and after drying. Variations of colour of fresh and dried ginger rhizomes of all forms dried at different temperatures are shown in Table. 4. Colour of ginger rhizomes in combination of L^* (from black to white), a^* (from green to red) and b^* (from blue to yellow) were slightly changed after drying. Lightness decreased with an increase in drying temperature for all samples except sliced and blanched samples. Lightness of blanched sliced samples and fresh rhizomes were not significantly changed with the drying temperature. Values of hue angle of all dried samples were significantly changed from the fresh samples but values of hue angle of blanched sliced samples were not significantly changed with the drying temperature. The sliced and blanched asparagus was dried at 50, 60 and 70 ^{0}C of drying temperature and there were some differences in colour indexes as shown in Fig. 10. From Fig. 10, we find that the lightness decreased at 60 ^{0}C but again increased at 70 ^{0}C, hue angle increased but there was no significant difference between hues for 60 and 70 ^{0}C. The chroma of the dried product increased for drying at 60 ^{0}C than chroma of ginger dried at 50 ^{0}C and then again decreased in 70 ^{0}C. This implies a small change in the colour intensity with increase in temperature. Thus, colour of the dried ginger rhizome for different drying air temperatures is almost same with a small increase in colour saturation.

Table 4. Colour variations of fresh and dried ginger rhizomes dried at different temperatures.

Treatments	Colour Value			
	L*	a*	b *	h* (^{0})
Fresh	71.43d	-6.73a	36.30e	100.61d
Non-blanched whole 50 ^{0}C	49.26b	4.6f	24.64bcd	79.39a
Non-blanched splitted 50 ^{0}C	49.76b	4.33f	26.18cd	80.59a
Non-blanched sliced 50 ^{0}C	63.36cd	0.54cd	25.14bcd	88.74b
Blanched whole 50 ^{0}C	49.28b	3.82ef	27.62d	82.06a
Blanched splitted 50 ^{0}C	62.01cd	0.45cd	24.33bcd	89.02b
Blanched sliced 50 ^{0}C	65.43cd	-1.06bc	24.15bcd	92.64bc
Non-blanched whole 60 ^{0}C	42.80ab	4.21f	24.31bcd	80.18a
Non-blanched splitted 60 ^{0}C	46.76b	5.15f	27.42cd	79.61a
Non-blanched sliced 60 ^{0}C	61.60cd	0.24bcd	25.14bcd	89.47b
Blanched whole 60 ^{0}C	49.28b	3.82ef	27.62d	82.06a
Blanched splitted 60 ^{0}C	60.28c	0.33cd	23.23bc	89.22b
Blanched sliced 60 ^{0}C	61.65cd	-1.06bc	26.85cd	92.12bc
Non-blanched whole 70 ^{0}C	47.80b	4.21f	23.64bcd	79.89a
Non-blanched splitted 70 ^{0}C	47.33b	-0.21bcd	16.67a	90.67bc
Non-blanched sliced 70 ^{0}C	35.81a	1.8de	17.13a	84.05a
Blanched whole 70 ^{0}C	40.62a	3.82ef	21.62b	80.04a
Blanched splitted 70 ^{0}C	36.67a	1.88de	17.21a	83.78a
Blanched sliced 70 ^{0}C	63.09cd	-1.83b	21.82b	94.85c

Common letter in the same column does not significantly differ at 5% level by Duncan’s Multiple Range Test (DMRT).

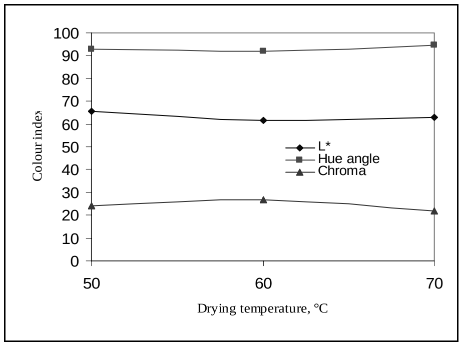


Fig. 10. Influence of drying on lightness (L^*), hue angle (h^*) and chroma (C) of sliced and blanched ginger.

Conclusions

Drying characteristics of ginger rhizomes of different shapes and sizes at three temperature levels of 50, 60, and 70 ^{0}C under blanched and non-blanched conditions were investigated. Blanching increases the drying rate and there is a significant difference between the drying curves for blanched and non blanched samples. The drying rate depends on shape and size of the ginger rhizomes. The highest drying rate was found for sliced samples of ginger rhizome followed by splitted and whole root samples. The moisture content of the whole ginger rhizome remain almost constant during the whole drying period and this is true for either blanched the whole samples or non-blanched the whole samples. The drying rate increased with the drying air temperature. The rate of increase of drying rate was relative low at low temperature. The drying time decreases with increase in drying temperature. Lightness of ginger rhizomes decreased with an increase in drying temperature for all samples except sliced and blanched samples.

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