Indian Journal of Agricultural Sciences **82** (4): 351–5, April 2012

Thin layer drying of ginger (*Zingiber officinale)* in a multi-rack type solar tunnel drier

E JAYASHREE[1] and R VISVANATHAN[2]

Indian Institute of Spices Research, Marikunnu PO, Kozhikode, Kerala 673 012

Received: 25 September 2010; Revised accepted:21 February 2012

ABSTRACT

Drying of ginger in a multi-rack type solar tunnel drier was studied. The drier consists of a UV-stabilized transparent plastic collector and a drying tunnel. Fresh ginger rhizomes were washed, peeled, spread in single layer in trays and dried from an initial moisture content of 594.01 to final moisture content of 9.89% (db). The temperature, relative humidity and solar intensity received under ambient and inside the solar tunnel drier were recorded. Mathematical modeling for thin layer drying showed that the diffusion approximation model best described the 'over all' drying process of ginger in a solar tunnel drier. The 'over all' effective moisture diffusivity of ginger in solar tunnel drier was 1.82×10^{-7} m^2/s. The essential oil and oleoresin content of solar tunnel dried ginger were 2.0 and 4.5%, respectively and was at par with the quality of sun dried ginger. However, the microbial load of solar tunnel dried ginger was 6.12 log cfu/g where as for sun-dried ginger it was 6.69 log cfu/g and hence solar tunnel drying was considered superior.

Key words: Drying kinetics, Effective moisture diffusivity, Ginger, Quality, Solar tunnel drying

Ginger (*Zingiber officinale* L.) is an underground rhizome valued as fresh vegetable, dry ginger spice and as preserved crystallized ginger. India is the largest producer and consumer of ginger. Fully matured ginger rhizomes harvested at about 80–82% moisture content is used for making dry ginger. The fresh rhizomes are scraped with bamboo splits to remove the outer skin to accelerate drying process (Balakrishnan 2005). Traditionally, ginger is sun dried to safe moisture content of 10% by spreading it in single layer in open yard which takes 7–10 days for complete drying. The yield of dry ginger is 19–25% of fresh ginger depending on the variety and climatic zone (IISR 2005). The dry ginger so produced is known as the rough or unbleached ginger and bulk of the ginger produced in Kerala are of this quality. Kerala accounts for over 60% of the total dried ginger production and about 90% of India's ginger export trade (Madan 2005).

Solar tunnel drier (STD) uses solar energy as source of heat for drying the produce and can be an efficient drying system for both farm and industrial level drying. Due to higher cost of fossil fuel and uncertainty regarding its future cost and availability, the use of solar energy in food processing will increase in the near future. Solar driers gives faster drying rates by heating the air to 10 to 20°C above ambient, which causes the air to move faster through the drier and reduces the humidity of drying air (Bala *et al*. 2003). Hence the present study was conducted to evaluate the STD for drying ginger rhizomes, to obtain the drying characteristics curves in a STD and to determine the quality of dried ginger.

MATERIALS AND METHODS

The experiments on solar drying of ginger were conducted at Agricultural Engineering College and Research Institute, Coimbatore, Tamil Nadu during April 2009. A tunnel drier of size 2 m × 3 m and height of 2 m was fabricated and installed on a concrete surface orienting towards east-west direction. The hoop structure was covered by UV-stabilized transparent polyethylene sheet (50 microns) to form the drying chamber (Fig 1). A curtain type door of size 1.6 m × 1 m made of the same material was provided in front of the solar tunnel drier. Natural ventilation to the drier was provided at the bottom of the door sheet using nylon mesh of size 800 mm × 400 mm. It served as air inlet to the drier. The experiments were carried between 9 and 17 hr. The temperature and relative humidity of ambient and heated air at different heights (0, 40, 80, 120 and 200 cm) inside the drier were measured using a digital temperature and relative humidity meter (EQUINOX, EQ-321 S). The velocity of the ambient and drying air was measured with an anemometer (PROVA Instrument INC, AVM – 05) which can measure air

---

[1] Scientist (SS) (e mail: ejayasree05@yahoo.com);

[2] Professor and Head (e mail: drrviswanathan@rediffmail.com), Department of Food and Agricultural Process Engineering, Tamil Nadu Agricultural University, Coimbatore, Tamil Nadu 641 003

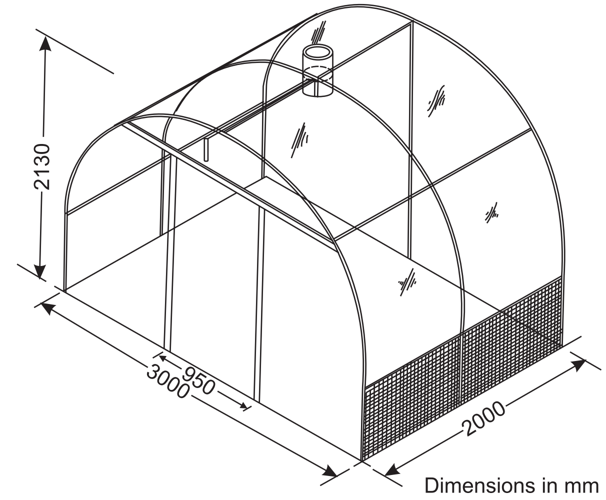


Fig 1 Schematic view of solar tunnel drier

velocity in the range 0–45 m/s. The solar radiation was measured both inside and outside the solar tunnel drier using a sunmeter. All the weather parameters were recorded at 1 hr interval.

Freshly harvested ginger rhizomes (40 kg) obtained from local market was mechanically washed and peeled partially. The ginger was spread in perforated stainless steel trays of size 790 × 400 × 300 mm with loading intensity of 2kg/tray. Totally there were 20 trays arranged in two racks. In each rack, 10 trays were arranged in five rows one below the other. The trays in the rack were not rearranged till the end of five days. After five days, the bottom trays were brought to the top and consecutively every day the trays were rearranged. Drying was carried till the weight reduction was constant.

The moisture content data at different experimental mode were converted into the moisture ratio (MR) expression and curve fitting with drying time were carried for six drying models (Table 1). The coefficient of determination R^2 was the primary criterion for selecting the best equation to describe the drying curve. In addition, the reduced chi-square (χ^2), root mean square error analysis (RMSE) and mean bias error (MBE) were calculated to evaluate the efficiency of fitting a model to the experimental data. The highest value of R^2 and the lowest values of χ^2, RMSE and MBE were used to determine the best fit (Togrul and Pehlivan 2002).

Table 1 Thin layer drying models

Name	Model	Reference
Newton	$MR = e^{-kt}$	Panchariya *et al.* (2002)
Page	$MR = e^{-kt^n}$	Lopez *et al.* (2000)
Modified page	$MR = e^{(-kt)^n}$	Ozdemir and Devres (1999)
Diffusion approximation	$MR = ae^{(-kt)} + (1-a)e^{(-kbt)}$	Ertekin and Yaldiz (2004)
Two-term exponential	$MR = ae^{(-kt)} + (1-a)e^{(-kat)}$	Ertekin and Yaldiz (2004)
Overhults	$MR = e^{[-(kt)^n]}$	Overhults *et al.* (1973)

These statistical parameters were calculated as follows:

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

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

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

where, $MR_{exp,i}$ is the ith experimentally observed moisture ratio, $MR_{pre,i}$ is the ith predicted moisture ratio, N is the number of observations, n is the number of constants in the model.

The effective moisture diffusivity of ginger was calculated using the method of slopes by plotting ln $((M-M_e)/(M_0-M_e))$ versus drying time (Geankoplis 2003).

The quality of dry ginger was determined in terms of its essential oil content estimated as per the method described by AOAC (1975) using modified Clevenger apparatus, oleoresin content by the method of ASTA (1968), crude fibre content by the method suggested by Sadasivam and Manickam (2008) and moisture content was analyzed in a fully automatic moisture meter (MA-50). The total plate count was determined by serial dilution technique as enumerated by Ranganna (1986).

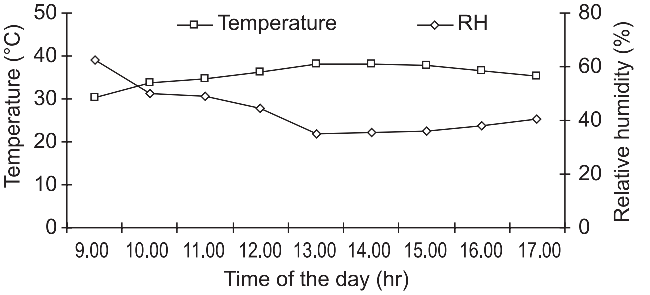
About 10 kg of ginger was sun-dried to compare the quality of dry ginger with obtained from solar tunnel-dried. The time required for complete drying by both the methods was also studied. The experiments were repeated thrice and the average values were reported. Sigma Plot (ver 6.0) statistical software was used to analyze the data obtained during drying and for mathematical modeling of drying curves.

RESULTS AND DISCUSSION

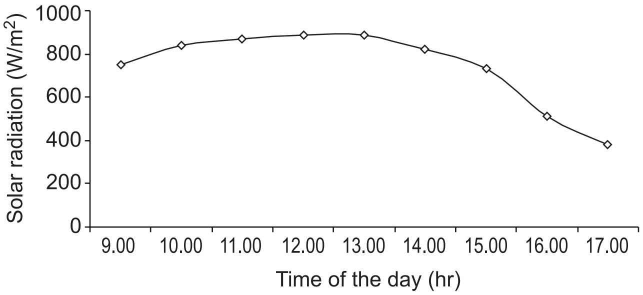
The average weather parameters for April 2009 recorded during the period of study indicated that temperature increased from a minimum of 30.3°C at 9 hr to a maximum of 38.1°C at 13 hr (Fig 2a). The average relative humidity decreased from 62.47% at 9 hr to 35.09% at 13 hr, which corresponded to the time when maximum solar radiation of 889.38 W/m^2 was obtained (Fig 2b). The average wind speed decreased from 0.5 m/s at 9 hr to 0.1 m/s at 13 hr and then increased to 1.3 m/s at 17 hr (Fig 2c).

Temperature, relative humidity and solar intensity inside the solar tunnel drier

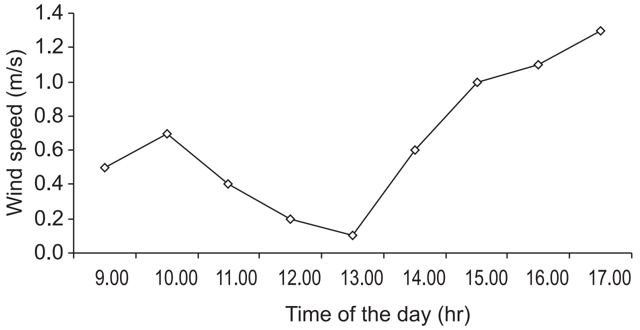
The temperature inside the solar tunnel drier increased



2a Average ambient temperature and relative humidity



2b Average solar radiation



2c Average wind speed

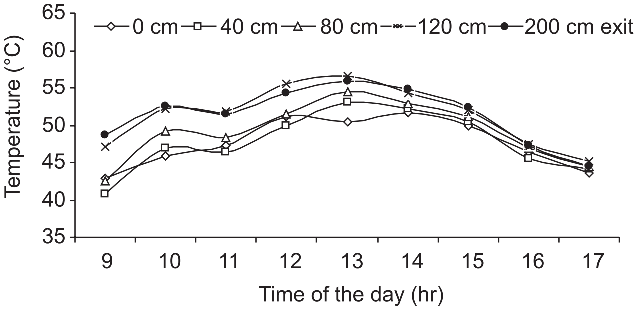
Fig 2 Variation in weather parameters for a day during April 2009 (mean values of five consecutive days of the month)

with the advance of time from 9hr to 13hr and then decreased. Similarly, increase in temperature was also observed with the increase in height of the drier. Inside temperature varied from a minimum of 40.8°C at 9 hr at 40 cm height to a maximum of 56.7°C at 13 hr at 120 cm height to (Fig 3a). The corresponding variation in the ambient temperature was 30.3°C at 9 hr and 38.1°C at 13 hr. The results showed that the temperature inside the solar tunnel drier was more by 10.5 to 19.4°C than the ambient temperature. Similar observation was reported by Beena and Fuller (2002) during drying of pineapple.

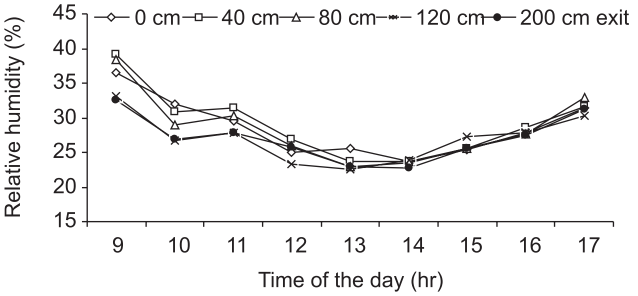
The relative humidity inside the solar tunnel drier decreased with the advance of time from 9 hr to 13 hr and then increased. The maximum relative humidity of 39.1% was recorded at 9hr, while the minimum relative humidity of 22.5% at recorded at 13 hr (Fig 3b). The corresponding ambient relative humidity at 9 hr and 13 hr were 62.5 and 31.8%, respectively. The results obtained indicated that the ambient relative humidity was generally higher than that of the tunnel drier and the difference varied between 9.3 and 23.4%. Joy *et al.* (2001) reported high relative humidity in ambient air when compared to the air inside the drier.

The intensity of solar radiation increased with the progress of time from 9 hr to 13 hr and then decreased. The average solar radiation inside the drier increased from 678.88 W/m^2 at 9hr to a maximum of 850.75 W/m^2 at 13 hr (Fig 3c). The corresponding average ambient solar radiations received were 749.29 and 889.39 W/m^2. The result obtained is in agreement with the results reported during drying of pineapple in a solar tunnel drier by Bala *et al.* (2003)

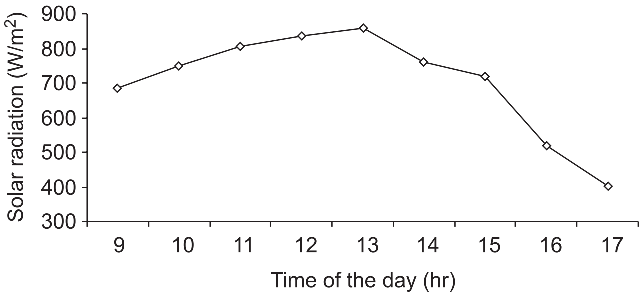
During drying of ginger in a multi-rack tray type solar tunnel drier it was observed that there was variation in moisture content, moisture ratio and drying rate as the tray levels varied (Fig 4). The five rows of trays in the rack were



3a Temperature at different heights



3b Relative humidity at different heights

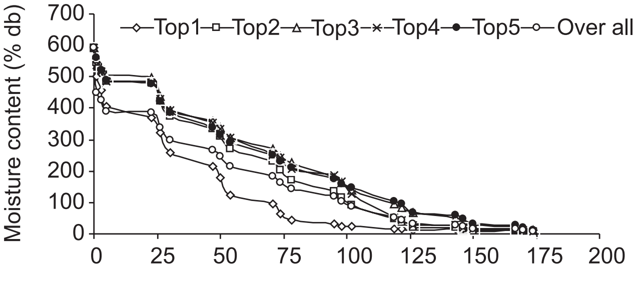


3c Solar radiation received

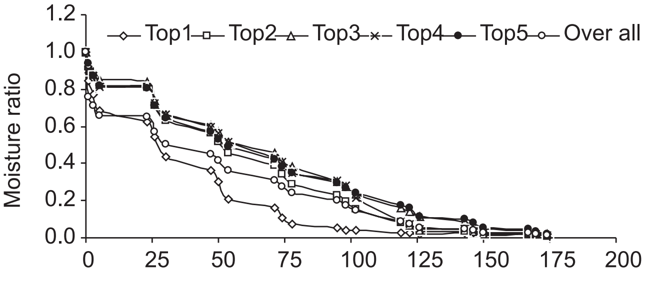
Fig 3 Variations in temperature, relative humidity and solar radiation inside a solar tunnel drier with ginger designated as ‘Top I’, ‘Top II’, ‘Top III’, ‘Top IV’ and the lowest was ‘Top V’.

Effect of tray levels on moisture content

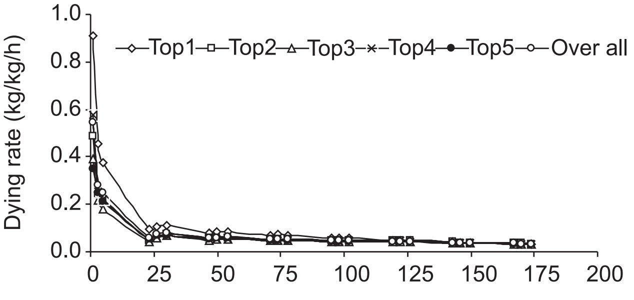
Ginger was dried from an initial moisture content of about 594.01% (db) to a final moisture content of about 10% (db). It was observed that drying was faster for ginger placed in the topmost tray (Fig 4a). To get typical characteristics curves, the trays were left undisturbed till five days of drying. After that, the bottom most trays were brought to the top and rearranged every day to get uniformly dried produce. At the end of eighth day of drying, the moisture content of ginger in tray levels ‘Top I’, ‘Top II’, ‘Top III’, ‘Top IV’ and ‘Top V’ were 10.34, 9.39, 10.3, 9.8 and 10.6% (db), respectively. The results obtained in the present study is in agreement with the results obtained by Beena and Fuller (2002) for drying of pineapple slices at different tray levels in a natural convection solar drier with biomass back up.



4a Plot of drying time and moisture content



4b Plot of drying time and moisture ratio



4c Plot of drying time and drying rate

Fig 4 Drying characteristics of ginger in solar tunnel drier

Effect of tray levels on moisture ratio

The reduction in moisture ratio for the tray levels ‘Top I’’, ‘Top II’, ‘Top III’, ‘Top IV’ and ‘Top V’ after five days of drying were 0.03, 0.08, 0.16, 0.09 and 0.17, respectively (Fig 4b). This showed that the lower trays contain more moisture than the top trays. During the final hour of drying, the moisture ratio reduced to 0.02, 0.01, 0.02, 0.02 and 0.02 for the tray levels ‘Top I’, ‘Top II’, ‘Top III’, ‘Top IV’ and ‘Top V’ respectively.

Effect of tray levels on drying rate

At the end of first hour, the drying rate of ginger for the tray levels ‘Top I’, ‘Top II’, ‘Top III’, ‘Top IV’ and ‘Top V’ were 0.91, 0.49, 0.39, 0.58 and 0.35 kg (moisture removed)/ kg (dry matter)/hr. It was thus clear that the drying rate was higher at the first level of tray. At the end of fifth day, the drying rate reduced to 0.048, 0.046, 0.042, 0.041 and 0.045 kg (moisture removed)/kg (dry matter)/hr. Finally, towards the end of drying, the drying rate reduced to 0.034 kg/kg/hr for all the tray levels inside the solar tunnel drier (Fig 4c). The difference in drying rate was due to the temperature gradient which was maintained inside the drier initially at the beginning of the day which narrowed down by noon. The drying rate decreased as the drying progressed from morning to evening. This may be due to the hardening of outer tissues and thereby reducing the removal of moisture from ginger. The results obtained in the present study agree well with the results reported for pineapple drying by Beena and Fuller (2002).

Mathematical modeling for solar tunnel drying of ginger

Moisture ratio expression of ginger dried in solar tunnel drier were fitted to six thin layer models and the values of drying constants with their corresponding statistical parameters like R^2, RMSE, MBE and χ^2 were determined. In case of solar tunnel drying of ginger, diffusion approximation model gave comparatively higher R^2 value of 0.98 for the ‘overall’ drying. The values of χ^2, RMSE and MBE were 0.04, –0.01 and 0.002, respectively which were lower for diffusion approximation model when compared to the other models. Hence, diffusion approximation model was assumed to represent the thin layer drying behaviour of ginger in solar tunnel drier. The predicted moisture ratios are in good agreement with the observed values and therefore it can be concluded that diffusion approximation is relatively better than the other five models.

Effective moisture diffusivity

The effective moisture diffusivity for drying of ginger in solar tunnel drier varied from 2.02×10^{-7} m^2/s for the top most level of trays to 1.58×10^{-7} m^2/s for the trays at bottom (Table 2). The ‘over all’ effective moisture diffusivity of ginger in solar tunnel drier was 1.82×10^{-7} m^2/s. Kaleemullah and Kailappan (2006) reported that the effective moisture

Table 2 Effective moisture diffusivity for drying of ginger in different layers in solar tunnel drying

Tray level	Effective moisture diffusivity (m^2/s)
'Top I'	2.02×10^{-7}
'Top II'	2.12×10^{-7}
'Top III'	1.67×10^{-7}
'Top IV'	1.93×10^{-7}
'Top V'	1.58×10^{-7}
Overall	1.82×10^{-7}

diffusivity of chillies increased from 3.78×10^{-9} to 7.10×10^{-9} m^2/s as the drying air temperature increased from 50 to 65°C.

Sun drying of ginger

Drying of ginger in open cemented yard took eight days to dry from initial moisture content of 594.01% (db) to final moisture content of 10% (db).

Quality evaluation of dried product

It was observed that the biochemical quality parameters like essential oil content (2.0%), oleoresin content (4.5%) and crude fibre content (2.4%) of solar tunnel dried ginger were at par with sun dried ginger (Table 3). However, the microbial load of solar tunnel dried ginger was lower (6.12 log cfu/g) than the sun dried ginger (6.69 log cfu/g). Hence the quality of solar tunnel-dried ginger was considered superior to sun-dried ginger.

Table 3 Quality parameters of ginger dried by different drying methods

Drying method	Essential oil content (%)	Oleoresin content (%)	Moisture content (%)	Crude fibre (%)	Microbial load (log cfu/g)
Sun dried	2.00	4.60	9.82	2.50	6.69
Solar tunnel dried	2.00	4.50	9.65	2.40	6.12

It may be concluded that drying of ginger in a multi-rack type solar tunnel drier took eight days for drying from an initial moisture content of 594.01% (db) to final moisture content of 10% (db). The essential oil and oleoresin content of solar tunnel dried ginger were 2.0% and 4.5% respectively and was at par with sun-dried ginger. The microbial load of solar tunnel-dried ginger was 6.12 log cfu/g, whereas for sun-dried ginger it was 6.69 log cfu/g. Diffusion approximation model represented the thin layer drying behaviour of ginger in solar tunnel drier. The overall effective moisture diffusivity for solar tunnel drying of ginger was 1.82×10^{-7} m^2/s.

REFERENCES

AOAC. 1975. *Official Methods of Analysis,* 563 pp. Association of Official Analytical Chemists, Benjamin Franklin Station, Washington.

ASTA. 1968. *Official Analytical Methods*. 2nd edn, American Spice Trade Association, New Jersey.

Bala B K, Mondol M R A, Biswas B K, Daschowdury B L and Janjai S. 2003. Solar drying of pineapple using solar tunnel drier. *Renewable Energy* **28**: 183–90.

Balakrishnan K V. 2005. Postharvest and industrial processing of ginger. (*in*) *Ginger-The Genus Zingiber,* 391–434 pp. Ravindran, P N and Nirmal Babu K (Eds.). CRC Press, Massachusetts.

Beena B and Fuller R J. 2002. Natural convection solar drier with biomass back-up heater. *Solar Energy* **72**: 75–83.

Ertekin C and Yaldiz O. 2004. Drying of eggplant and selection of a suitable thin layer-drying model. *Journal of Food Engineering* **63**: 349–59.

Geankoplis C J. 2003. Drying of Process Materials. In: *Transport Processes and Separation Process Principles,* 4th edn, pp 559–611. Prentice-Hall of India Private Ltd, New Delhi.

IISR. 2005. *Ginger-Extension Pamphlet*. Indian Institute of Spices Research. Calicut. Kerala.

Joy C M, George P P and Jose K P. 2001. Solar tunnel drying of red chillies. Journal *of Food Science Technology* **38**: 213–16.

Kaleemullah S and Kailappan R. 2006. Modelling of thin-layer drying kinetics of red chillies. *Journal of Food Enineering* **76**: 531–7.

Lopez A, Iguaz A, Esnoz A, and Virseda P. 2000. Thin layer drying behaviour of vegetable wastes from wholesale market. *Drying Technology* **18**: 995–06.

Madan M S. 2005. Production, marketing and economics of ginger. (in) *Ginger-The Genus Zingiber,* pp 435–68 Ravindran, P N and Nirmal Babu K (Eds). CRC Press, Massachusetts.

Overhults D D, White G M and Hamilton H E, Ross I J, 1973. Drying soybeans with heated air. *Transactions of American Society of Agricultural Engineering* **16**: 112–3.

Ozdemir M and Devres Y O. 1999. The thin layer drying characteristics of hazelnuts during roasting. *Journal of Food Engineering* **42**: 225–33.

Panchariya P C, Popovic D, and Sharma A L. 2002. Thin-layer modeling of black tea drying process. *Journal of Food Engineering* **52**: 349–57.

Ranganna, S. 1986. *Handbook of Analysis and Quality Control for Fruit and Vegetable Products*. pp 646–56 Tata McGraw Hill Pub. Co. Ltd, New Delhi.

Sadasivam B and Manickam A. 2008. *Biochemical Methods*. 3rd edn. pp 18, New Age International (P) Ltd, New Delhi.

Togrul I T and Pehlivan D. 2002. Mathematical modeling of solar drying of apricots in thin layers. *Journal of Food Engineering* **55(3)**: 209–16.