Studies on thin layer drying characteristics of ginger (*Zingiber officinale*) in a mechanical tray drier

(Manuscript Received: 21-06-12, Revised: 27-10-12, Accepted: 20-12-12)

Keywords: Drying kinetics, effective moisture diffusivity, ginger, mechanical drying, quality

Ginger (*Zingiber officinale)* is an under ground 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 per cent wet basis moisture content is used for making dry ginger. Peeling accelerates the drying process and is done with bamboo splits to remove the outer skin (Balakrishnan, 2005). Traditionally, ginger is sun dried to safe moisture content of 10 per cent by spreading it in single layer in open yard which takes about 10 days for complete drying. The yield of dry ginger is 19-25 per cent of fresh ginger depending on the variety and climatic zone (Anonymous, 2005). Drying of ginger to safe moisture content is a problem especially in the North Eastern regions of India where the sun shine intensity is not sufficient for complete drying. Improper drying leads to the problem of aflatoxin contamination during storage and the product become unfit for human consumption. The present study was conducted to evaluate an electrically operated tray drier for drying ginger rhizomes, to obtain the drying characteristics curves and to determine the quality of mechanically dried ginger.

The experiments on mechanical drying of ginger was carried in a laboratory model cross flow type tray drier (M/s. Kilburn oven, 024E) (Fig.1) at Agricultural Engineering College and Research Institute, Coimbatore, Tamil Nadu during April 2009. The drier consists of a drying chamber of size 830 x 880 x 830 mm provided with 9 heating coils each with a capacity of 1000 watts, placed vertically on either side of the drying chamber to supply the necessary heat for the incoming air. A centrifugal blower of capacity 0.45 $m^3 min^{-1}$, run by a 0.5 hp electric motor is fixed at the delivery side of the drier.

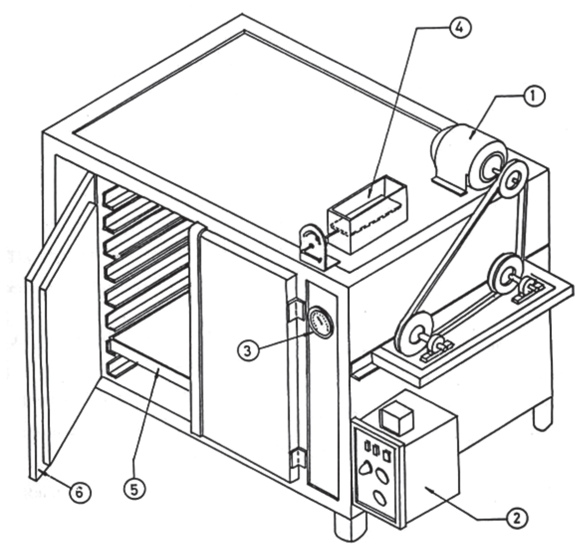

Fig. 1. Isometric diagram of mechanical tray drier
(1) Motor (2) Panel board (3) Temperature indicator
(4) Hot air outlet (5) Tray (6) Door

Drying of ginger was done at drying temperature of 60 °C and the temperature inside the drying chamber was regulated using a thermostat. The butterfly valve was so adjusted that the exhaust air flow rate was 0.2 m s^{-1} and this helped to remove the moisture from the produce during drying. The drier was run under no load condition and the temperature profile inside the drier was studied.

Freshly harvested ginger rhizomes (36 kg) were spread in 12 trays at a loading intensity of 3 kg $tray^{-1}$ of size 790 x 400 x 33 mm and the trays were arranged one below the other in six rows. The distance between the trays was 12.5 cm. The trays in each row from top to bottom was designated as T I to T VI and 'over all' indicates the general drying process inside the drier irrespective of the tray position. Drying of ginger was conducted from 9 AM to 5 PM at drying air temperature of 60 °C. During drying, the trays inside the drier were not rearranged till the end of five days and after that, the bottom trays were brought to the top and consecutively every day the trays were rearranged till the mass reduction of ginger was constant. The drier was run under no load condition and the temperature profile inside the drier was studied.

For mathematical modeling of ginger drying, the moisture content data at different experimental modes were converted into the moisture ratio (MR) expression and curve fitting with drying time was carried for six drying models (Table 1). The

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)

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).

These statistical parameters were calculated as follows:

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

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

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

where, $MR_{exp,i}$ is the i[th] experimentally observed moisture ratio, $MR_{pre,i}$ is the i[th] 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 (Sartorius, Germany; MA-50). About 10 kg of ginger was sun dried to compare the quality of dry ginger with that obtained from mechanical drier. The time required for complete drying by both the methods was also studied. Sigma Plot (ver 6.0) statistical software was used to analyze the data obtained during drying and for mathematical modeling of drying curves.

During drying ginger in a mechanical tray drier it was observed that there was reduction in moisture content, moisture ratio and drying rate as the drying time progressed. The moisture content of ginger during drying reduced from an initial value of 419.93 per cent dry basis (d.b.) to a final value of less than 10 percent (d.b.) (Fig. 2a). To get typical drying characteristic curves, the trays were left undisturbed till the end of five days and the moisture content reduced from 419.93 per cent (d.b.) to 58.67, 31.54, 58.23, 89.17, 102.77 and 149.91 per cent (d.b.), respectively for ginger placed in the six trays from top to bottom. After five days, the bottom most trays were brought to the top and rearranged every day to obtain uniformly dried produce. At the end of eighth day, drying was almost complete and the moisture content of the tray levels T I to T VI were 7.34, 8.57, 7.80, 8.75, 9.62 and 9.45 per cent (d.b.), respectively.

The moisture ratio at the end of first day of drying for the tray levels T I to T VI were 0.81, 0.70, 0.78, 0.83, 0.81 and 0.89, respectively (Fig. 2b). The corresponding moisture ratios at the end of fifth day were 0.14, 0.08, 0.14, 0.21, 0.25 and 0.36, respectively. After the rearrangement of trays for uniform drying, the drying was completed by the end of eight days and the moisture ratio for the last hour of drying was 0.02 for all the tray levels.

The drying rate of ginger, at the end of first hour of drying for the trays T I to T VI were 0.13, 0.20, 0.15, 0.16, 0.14 and 0.15 kg kg^{-1} h^{-1}. It was thus obvious that the drying rate was higher in the tray level 'Top II'. At the end of five days, the drying rate for the corresponding tray levels were 0.035, 0.038, 0.035, 0.033, 0.031 and 0.027 kg kg^{-1} h^{-1}, respectively (Fig. 2c). Towards the end of drying, the drying rate was 0.023 kg kg^{-1} h^{-1} for all the tray levels. The non uniformity in drying for different tray levels was due to the temperature gradient which existed in the drier which caused differences in drying at different tray levels (Fig. 3).

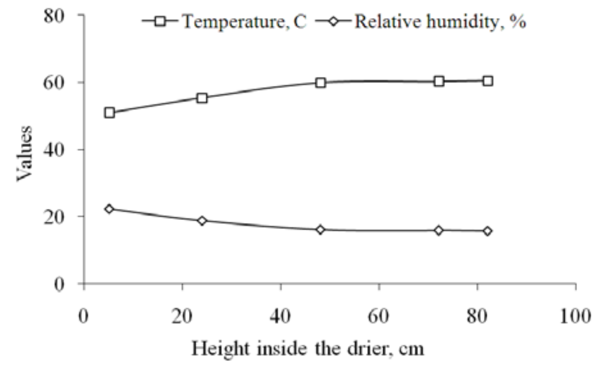

Fig. 3. Variation in temperature and relative humidity inside the tray drier

For obtaining mathematical models, moisture ratio expression was fitted to six thin layer drying models. In all the cases, it was found that the values of R^2 were greater than 0.90 indicating a good fit. But, diffusion approximation model gave comparatively higher R^2 values (0.989) and lower χ^2 (0.001), RMSE (0.03) and MBE (-0.01) values. Hence, diffusion approximation model was assumed to represent the thin layer drying behaviour of ginger in mechanical tray drier. Fig. 4 shows that the predicted moisture ratios are in good agreement with the experimental values ('over all') and therefore it was concluded that diffusion approximation was better than the other five models. Sobukola *et al.* (2007) reported that for convective hot air drying of blanched yam slices in a laboratory convective hot air drier, the approximation of diffusion model was found to satisfactorily describe the kinetics of air-

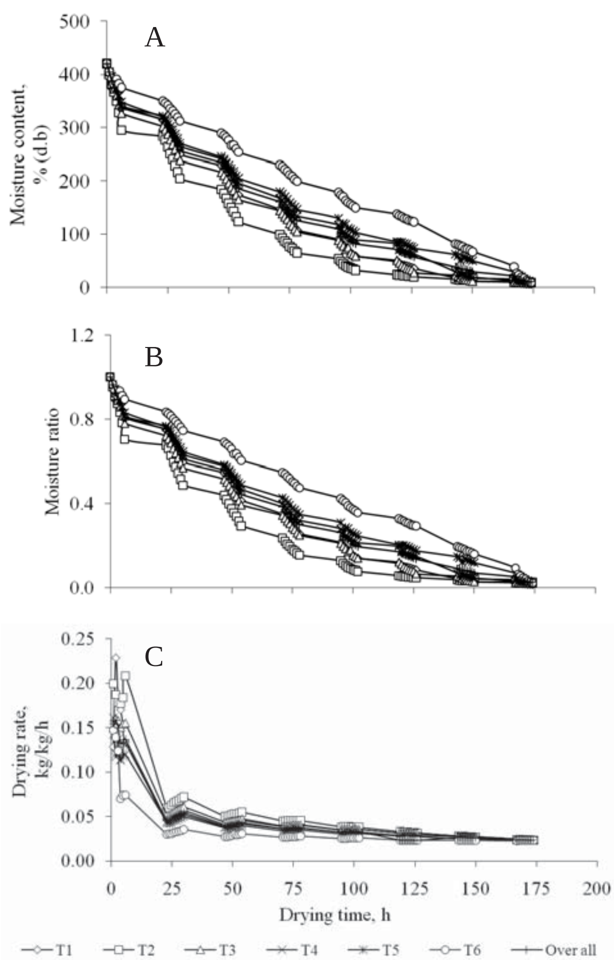

Fig. 2. Drying characteristics of ginger in mechanical tray drier. Plots of (A) drying time andmoisture content; (B) drying time and moisture ratio; (C) drying time and drying rate

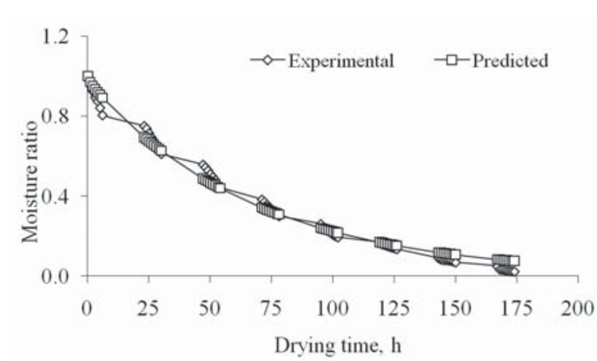

Fig. 4. Experimental and predicted moisture ratios for drying ginger in a mechanical tray drier using diffusion approximation model

drying of blanched yam slices. The effective diffusivity values varied between 7.62×10^{-8} to 9.06×10^{-8} m^2 s^{-1} and increased with increase in temperature.

The effective moisture diffusivity of ginger while drying in a mechanical tray drier varied from 1.91 m^2 s^{-1} to 1.31 x 10^{-7} m^2 s^{-1} for ginger placed in the top and bottom trays (Table 2). The 'over all' effective moisture diffusivity of ginger in a mechanical tray drier was 1.59 x 10^{-7} m^2 s^{-1}. The effective moisture diffusivity of green beans was found to vary between 2.64 to 5.71 x 10^{-9} m^2 s^{-1} when the drying air temperature varied from 50 to 70 °C (Doymaz, 2005).

Table 2. Effective moisture diffusivity for drying of ginger in different layers in mechanical tray drier

Tray levels	Effective moisture Diffusivity (m^2 s^{-1})
T I	1.91 x 10-7
T II	1.82 x 10-7
T III	1.82 x 10-7
T IV	1.75 x 10-7
T V	1.39 x 10-7
T VI	1.31 x 10-7
Over all	1.59 x 10-7

The ginger dried in tray drier was evaluated for its quality parameters like essential oil content, oleoresin content, moisture content and crude fibre content (Table 3). It was observed that there was significant reduction in essential oil content of ginger dried in tray drier (1.60 %) compared to sun drying. The oleoresin content was 4.5 per cent, crude fibre content was 2.4 per cent, the final moisture content was 9.4 per cent and these values were at par with the values of the sun dried ginger. Though there was reduction in essential oil content, mechanical drying is the only alternative when there is no sufficient solar intensity for sun drying.

Table 3. Quality parameters of ginger dried by mechanical drying

Drying type	Essential oil (%)	Oleoresin (%)	Moisture content (%)	Crude fibre (%)
Mechanical drying	1.6	4.5	9.4	2.4
Sun drying	2.0	4.6	9.8	2.5
CD (5 %)	0.16	0.41	0.87	0.22
SED	0.06	0.14	0.31	0.08

It may be concluded that drying of ginger in an electrically operated tray drier took 8 days for drying from an initial moisture content of 419.93 per cent (d.b.) to final moisture content of 8.59 per cent (d.b.) when the drier was operated for 8 h a day. Modeling of drying data showed that diffusion approximation model best described the drying process. The 'over all' effective moisture diffusivity of ginger in tray drier was 1.59 x 10^{-7} m^2 s^{-1}. The quality of ginger dried in mechanical tray drier was found to contain 1.6 per cent essential oil, 4.5 per cent of oleoresin, 9.42 per cent of moisture content and 2.3 per cent of crude fibre.

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