International Journal of Food and Fermentation Technology
Citation: *Int. J. Food Ferment. Technol.*, **14**(01): 275-289, June 2024
DOI: 10.30954/2277-9396.01.2024.2

ASSOCIATION FOR AGRICULTURE ENVIRONMENT AND BIOTECHNOLOGY

Research Paper

Solar Drying of Beetroot Slices and Its Quality Evaluation

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Paper No.: 286 **Received:** 19-02-2024 **Revised:** 21-05-2024 **Accepted:** 02-06-2024

ABSTRACT

The drying characteristics of beetroot slices were investigated by solar drying method of 4 mm thickness beetroot slices, beetroot slices dried from 611.019% (d.b) moisture content 6.095% (d.b) in the solar dryer in 33 hr. Eight drying models i.e. Newton model, Page model, Henderson and Pabis, Exponential, Modified page, Thompson, Logarithmic, Modified page equation II etc. were fitted to the experimental data on moisture ratio with respect to time. Henderson and Pabis drying model best fitted with $r^2 = 0.9914$; RMSE = 0.00038 and $\chi^2 = 0.0301$ to experimental moisture ratio with respect to time. Effective Diffusivity (D_{eff}) at time (t) for Beetroot slices drying by Solar drying was 2.53154×10^{-8} m^2/s. Variation in ambient air temperature ranging from 29.5 and 51.0°C, product temperature ranging between 19.4 to 49.56°C and humidity ranging between 35 to 60 %. Effect of quality parameters i.e. acidity, TSS, pH, reducing sugar, total sugar, moisture, hardness, and color (L, a and b value) on fresh beetroot slices and dried beetroot slices after drying at solar drying were determined and discussed at $p \leq 0.05$. Total soluble solid of fresh beetroot slices was 10 ± 2.00°B and solar drying total soluble solid content beetroot slices was 57.33 ± 0.58°B, the pH of beetroot slices before drying was 7.27±0.24 and then after solar drying pH of beetroot slices was 6.57 ± 0.15. The titratable acidity of the beetroot slices before drying was 0.31 ± 0.21% and it increases upto 1.28 ± 0.13%, the reducing sugar content of beetroot slices before drying was 0.29 ± 0.03% and then after solar drying reducing sugar content of beetroot slices was 2.93 ± 0.23%, the total sugar content of beetroot slices before drying was 18.80 ± 0.56% and then after solar drying total sugar content of beetroot slices was 41.48 ± 1.08%. The *L, a, b* value of beetroot slices before drying was 33.69 ± 0.12, 31.50 ± 0.85 and 9.10 ± 0.16 respectively, then after solar drying L, a, b value of beetroot slices was 26.108 ± 0.12, 28.78 ± 0.12 and 13.636 ± 0.06 respectively.

Keywords: Solar drying, moisture ratio, drying behavior, drying models, effective diffusivity (D_{eff}), activation energy (E_a), and chemical properties

Beetroot (*Beta vulgaris L.*) is botanically classified as an herbaceous biennial from the chenopodiaceae family and has several varieties with bulb colors ranging from yellow to red (Singh *et al.* 2013). It is commonly known as '*chukander*', is mainly cultivated in India for its juice and vegetable value. It is ranked among the 10 most powerful vegetables with respect to antioxidant capacity described to total phenolic content of 50-60 μmol/dry weight (Kahkonen *et al.* 1999; Vinson *et al.* 1998). The plant consists of roots and a rosette of leaves. The sugar is formed by photosynthesis in the leaves and then stored in the roots. The main source of natural red dye is known as beetroot red (Ninfali and Angelina, 2013).

Beetroot is rich in valuable, active compounds such as carotenoids (Dias *et al.* 2009), betacyanines (Patkai, 1997), folates (Jastrabova *et al*. 2003), betanin, polyphenols, and flavonoids (Vali *et al.* 2007).

How to cite this article: Nale, S.A. and Swami, S.B. (2024). Solar Drying of Beetroot Slices and Its Quality Evaluation. *Int. J. Food Ferment. Technol.*, **14**(01): 275-289.

Source of Support: None; **Conflict of Interest:** None

Therefore beetroot ingestion can be considered a factor in cancer prevention (Kapadia *et al*. 1996).

Beetroot is popularly consumed as red food colorant, e.g. to improve the colour of tomato paste, sauces, desserts, jam and jellies, ice cream, sweets, and cereals (Kaur and Singh, 2014). The Beetroot being an alkaline food with pH from 7.5 to 8.0 has been acclaimed for its health benefits, in particular for its disease-fighting antioxidant potential, a significant amount of vitamin C and vitamin B_1 , B_2, niacin, B_6, B_{12} (Singh *et al*. 2013). Juice of beetroot is also consumed as a natural remedy for sexual weakness and to expel the kidney and blade stone (Sharma, 2014). Extract of a root possesses antihypertensive, hypoglycaemic, antioxidant (Ninfali *et al*. 2013), anti-inflammatory and hepatic-protective activities (Singh *et al*.,2013; Jain *et al*. 2011; Kujala *et al*. 2000). The claimed therapeutic use of beetroot includes its antitumor, carminative, emmenagogue, and haemostatic and renal protective properties, and it is a potential herb used in cardiovascular conditions (Vali *et al*. 2007). Beetroot is an excellent source of folate and a good source of manganese (USDA Nutritional Database, 2014). It is beneficial for digestive problems, such as constipation, for the skeletal system and a good circulation of blood. (Profir *et al*. 2013).

Dried beetroots can be consumed directly in the form of chips as a substitute for traditional snacks that are rich in tran's fatty acids (Aro *et al*. 1998; Krejcova *et al*. 2007) or after easy preparation as a component of instant food. Red beetroot powder, as a natural red food colorant, offers application in dry mixes (soups, Indian curry mixes), sweets, jam, jellies etc. the bright red color of beetroot is owing to a group of red pigments known as betalains. Betalains are antioxidants and have profound health benefits.

The solar drying process has certain advantages as it avoids the contamination of products by dust and dirt. Also it requires less surface area as compared to the open sun drying process for drying the product. So, improved drying methods are required for faster and more efficient drying and contamination-free dried products at lower cost.

Drying process reduces the content of moisture, and then chemical alteration helps minimize microbiological activity in the product during storage. Therefore the persistence of the product and its stability will increase. Dehydration improves food stability since it considerably reduces the water and microbiological activity of the material and minimizes physical and chemical changes during its storage, reduces spoilage, increases shelf life, reduction in product mass and gives added value as it is without chemical treatments. Drying is a process of moisture removal because of simultaneous heat and mass transfer (Dincer, 1998). It is also one of the conservation methods of agricultural products, which is most often used and is the most energy-intensive process in the industry (Dincer, 1998).

Knowledge of drying kinetics of the biological materials is essential to the design, optimization and control of the drying process. Various researchers have reported the drying characterization of fruits and vegetables by using a solar dryer for Bechoff *et al*. (2009) studied the effect of hot air, solar and sun drying on provitamin (A) retention in Orange fleshed sweet potato; Ratti and Mujumdar (1997) developed the modeling of shrinkage of the particle and numerical simulation for carrot and apple in solar dryer; Hassanain (2009) carried out experiments on solar drying of banana fruit; Janjai *et al*. (2009) developed a mathematical model for side loading type solar tunnel dryer by drying peeled longan; Bala *et al*. (2009) used solar tunnel dryer for drying of mushroom; Tunde- Akintunde *et al*. (2005) studied the influence of drying methods i.e. sun, solar and artificial air drying on drying of bell- pepper. No reports are available so far for drying of beetroot slices by solar drying. The objective of this study was to investigate the effects of drying temperature on the thin layer drying of the beetroot slices and to evaluate a suitable drying model for the describing drying process. The dehydrated product quality was also evaluated.

MATERIALS AND METHODS

Raw material

Beetroot(*Beta vulgaris* L.) of firm tubers were purchased from local market located at Agricultural Produce Market Committee, Vashi. The tubers were washed with the tap water thoroughly and the dirt was removed. After surface moisture removal the tubers were peeled by using hand peeler. The peeled tubers were sliced into 4 mm thicknesses.

Experimental setup for solar drying

The solar dryer were made from Bamboo purchased from market. The solar dryer of size 0.85 × 0.85 × 1.80 m (l × b × h) was designed. The drying chamber was 0.80 × 0.80 × 1.60 m (l × b × t). The dryer was designed for 5 kg capacity of beetroot slices and accommodates at least four [81 × 41 × 3.4 cm, (l × b × h)] perforated trays in solar dryer. The mesh size was 1 × 1 mm. The bamboos were cut at 180 cm height of each are fitted with the screws. The top of the dryer was made up of trapezoidal shape. The bamboos were applied with black color to absorb more heat by the dryer leads to enhancing the rate of drying. The distance between the two trays was 85 cm. The first compartment for placing the perforated trays was at 40 cm from the ground level and the second compartment was at 90 cm apart from the first compartment. This facilitates fixing up the two trays of size 81 × 41 cm (l × b) are accommodating in each compartment easily. An exhaust outlet was placed at the topmost central portion for removing the dried air inside the chamber. The structure was covered with UV protected polyethylene sheet 475 guage and with help the of adhesive gum. The inlet air was entered into the dryer from holes (size-6 cm)provide at the bottom of the dryer. The air circulates through the first tray and passing through to the next uppermtrays, before leaving holes at the top of the dryer. The holes are covered inside by fine mesh for better aeration, which enhances the drying rate. Fig. 1 solar dryer developed for the experiment. Beetroot slices were dried in solar dryer up to the final moisture content of 6.049 ± 2% (db) and corresponding observations like Product temperature, inside temperature, ambient air temperature, relative humidity etc were recorded. The samples were dried and also the weight loss of each sample were recorded at regular interval for 10 min for first 3 hours and each 30 minute still the constant weight was reached by using an electronic weighing balance and drying characteristics were studied. The experiment was triplicated for each treatment and corresponding data characteristics, moisture content versus time, drying rate versus moisture content and moisture ratio versus time were studied.

Fig. 1: Experimental setup for solar drying of beetroot slices

Moisture content

The moisture content of beetroot slices was determined as per AOAC, 2010. Initial moisture content of beetroot slices was calculated by the hot air oven at 105˚C ±1˚C for 24 hours. The final weight of beetroot slices were recorded after 24 hours. The moisture content of the beetroot slices was determined by following formula (Chakraverty, 1994).

$$\text{Moisture content (db) \%} = \frac{w_1 - w_2}{w_2} \times 100. \quad \text{... (1)}$$

Where,

W_1= Weight of sample before drying, *g*

W_2= Weight of sample after drying, *g*

Solar dryer parameter measurement

Humidity and ambient air temperature was measured using a digital thermo-hygrometer (Make: Crystalinstruments, Mumbai; Model: Temptec) with accuracy of 1°C and 5% RH. Air velocity of ambient air was measured by anemometer (Make: Lutron Electronics, Taiwan; Model: AM4202) having the accuracy of 0.1 $m.s^{-1}$. The product temperature measured by inserting the sensors into the product during the drying using a data logger (Make: Ambetronics; Model: TC800D). The initial moisture content, weight loss with respect to time during drying, final moisture content of the beetroot slices was also recorded. Drying was carried out up to 5 days. Three replication were taken for each experimental run.

Drying characteristics

Moisture content (%db) versus drying time (min) and drying rate (g of water removed /100 g of bone dry material/min) with respect to the moisture content was determined for solar drying of beetroot slices. Moisture ratio versus drying time (min) was also determined from the experimental data. The various mathematical models listed in Table 1 were fitted to the experimental data on moisture ratio versus drying time in min of beetroot slices dried with solar drying. The moisture ratio determines the unaccomplished moisture change, defined as the ratio of the free water still to be removed at time (t) over the initial total free water (Henderson and Pabis, 1961).

(a) Moisture ratio: The moisture ratio of beetroot slices was calculated on a wet basis using following formula (Chakraverty, 2003).

$$\frac{M - Me}{Mo - Me} \quad \text{...(2)}$$

Where,

MR = Moisture ratio

M = Moisture content at any time θ, %(db)

M_e = EMC, % (db)

M_0 = Initial moisture content, %(db)

(b) Drying rate

The drying rate of beetroot slices was calculated on dry basis using following formula (Chakraverty, 2003).

$$R = \frac{W_r}{T \times W_D} \times 100 \quad \text{...(3)}$$

Where,

R = Drying rate (g/min)

W_r = Amount of moisture removed (*g*)

T = Time taken (min)

W_D = Total bone dry weight of sample (*g*)

The root mean square error was for the best fit of the model was determines for higher r^2 values and lower MSE.

$$RMSE = \left[\frac{1}{N}\sum_{i=1}^{n}\left(MR_{\exp} - MR_{pre}\right)^2\right]^{1/2} \quad \text{... (4)}$$

Where,

MR_{exp}= experimental moisture ratio

MR_{pre}= predicted moisture.

N and n are the number of observations and the number of constants respectively (Togrul and Pehlivan, 2004).

1. Correlation regression coefficient and error analysis

The goodness of fit of the tested mathematical models to the experimental data was evaluated with the correlation coefficient (r^2), chi-square (χ^2) and the equation (5). The higher the r^2 value and the lower the chi-square (χ^2) and *RMSE* values, the better is the goodness of fit (Ozdemir *et al*. 1999; Ertekin & Yaldiz., 2004; Wang *et al*. 2007). According to Wang *et al.* (2007

a) reduced chi-square (χ^2) and root mean square error (*RMSE*) can be calculated as follows:

$$\chi^2 = \frac{\sum_{i=1}^{N}\left(MR_{\exp,i} - MR_{pre,i}\right)^2}{N-Z} \qquad \ldots(5)$$

Where,

$MR_{exp,i}$ = is the i^{th} experimental moisture ratio,

$MR_{pre,i}$ = is the i^{th} predicted moisture ratio,

N = is the number of observation, and

z = is the number of constant.

2. Effective moisture diffusivity

The effective moisture diffusivity is calculated by using the simplified Fick's second law of diffusion model (Doymaz, 2004) as given in equation (6).

$$\frac{\partial M}{\partial t} = D_{eff}.\nabla^2 M \qquad \ldots(6)$$

Where,

M = is moisture content (kg water/kg dry matter);

t = is the time (s);

D_{eff} = is the effective moisture diffusivity,(m^2/s);

∇^2 = is the differential operator.

The solution of Fick's second law in slab geometry, with the assumption that moisture migration was caused by diffusion, negligible shrinkage, constant diffusion coefficient and temperature was given by Crank (1975) as follows:

$$MR = \frac{8}{\pi^2}\sum_{i=1}^{n}\frac{1}{(2n-1)^2}\exp\left(\frac{-(2n-1)^2\,\pi^2 D_{eff'}}{4H^2}\right) \qquad \ldots(7)$$

Where,

H = is the half thickness of the slab m;

n = 1, 2, 3 … the number of terms taken into consideration.

For long drying time Equation (7) can be simplified further (Lopez *et al.* 2000; Doymaz, 2004) as:

$$\ln(MR) = \ln\frac{8}{\pi^2} - \frac{\pi^2 D_{eff'}}{4L^2} \qquad \ldots(8)$$

The diffusivities are typically determined by plotting the experimental drying data in the terms of *ln* (*MR*) vs drying time (t) in equation (8), because the plot gives a straight line with the slope as follows:

$$Slope = \frac{\pi^2 D_{eff}}{4L^2} \qquad \ldots(9)$$

Where,

L = half thickness

Evaluation of Quality parameters for the beetroot powder Product

1. Total soluble solids

Total soluble solids was determined for fresh slices and dried after solar drying by using a Refractometer (M/s. Atago, Japan) and the values were corrected at 20°C. The equipment was calibrated with distilled

Table 1: Mathematical models tested with the moisture ratio of beetroot slices

Sl. No.	Model	Equation	Reference
1	Newton	MR = exp (-kt)	Westerman, *et al.* 1973
2	Page	MR = exp ($-kt^n$)	Zhang and Litchfield, 1991
3	Henderson and Pabis	MR = a.exp (-kt)	Henderson and Pabis, 1961
4	Exponential	MR = exp (-kt)	Liu and Bakker-Arkema, 1997
5	Modified page	MR=exp($-(kt)^n$)	Zhang and Litchfield, 1991
6	Thompson	MR = a.exp ($-kt^n$) + bt	Sacilik *et al.* 2006
7	Logarithmic	MR= a.exp(-kt) + C	Zhu and Shen, 2014
8	Modified Page equation- II	MR= a.exp $(-kt)^n$	Zhang and Litchfield, 1991

water and the TSS of the beetroot juice before drying and slices powder after drying was determined by adding the 5 g sample into the 20 ml of distilled water and TSS were measured by hand refractometer. The experiments were replicated three times.

2. pH

pH of beetroot fresh slices and dried slices after solar drying was measured using a digital pH meter. The digital pH meter is first calibrated by using 4 pH and 7 pH buffer solution. The electrode was washed with distilled water and blot led with tissue paper. 10 ml of beetroot slice and dried slices powder was taken in beaker, then the tip of electrode and temperature probe then submerged in to the sample. The pH reading display on the primary LCD and the temperature on the secondary one. The pH of fresh beetroot slices and slices after solar drying was determined by three replications.

3. Titratable acidity

The titratable acidity of beetroot juice and slice powder after drying at solar drying was determined by Ranganna (1997). A known quantity of sample was blended in mortar and pestle with 20-25 ml distilled water. It was then transferred to 100 ml volumetric flask, made up the volume and filtered. A known volume of aliquot (10ml) was titrated against 0.1N sodium hydroxide (NaOH) solution using phenolphthalein as an indicator (Ranganna, 1997). The acidity was calculated as given below and the results were expressed as percent anhydrous citric acid. The three replications were carried out, and the average reading was reported.

$$\text{Titratable acidity (\%)} = \frac{N \times T \times E}{W \times V \times 1000} \times 100 \quad \ldots(10)$$

Where,

N = normality of alkali

T = titrate reading

E = equivalent mass of acid, g

W = weight of the sample, g

V = total volume of the sample, g

3. Reducing sugars

The reducing sugars was for beetroot juice and slice powder after drying at solar drying estimated by using Lane and Eynon Method with modifications suggested by Ranganna (1997). A known weight of beetroot slices was crushed with distilled water using lead acetate (4F5%) for precipitation of extraneous material and potassium oxalate (22%) to de-lead the solution. This lead free extract was used to estimate reducing sugars titrating against standard Fehling mixture (Fehling 'A' and 'B' in equal proportion) using methylene blue as an indicator to brick red endpoint. The three replications were carried out, and the average reading was reported.

$$\textit{Reducing sugar}\ \% = \frac{100}{\text{Burette reading}} \times \frac{\text{Volume prepared}}{\text{Inital volume}} \times GV \text{ of fehling's solution} \quad \ldots(11)$$

Where,

GV = Glucose value

4. Total sugars

Total sugars was estimated was for beetroot juice and slice powder after drying at solar drying by same procedure of reducing sugar after acid hydrolysis of an aliquot of deleaded sample with 50 percent of hydrochloric acid followed by neutralization with sodium hydroxide (40%) and calculated as below (Eq. 12). The experiment was repeated three times to get the replication.

$$\textit{Total sugar}\ (\%) = \frac{\text{Factorx Dilution}}{\text{Titrereading} \times \text{Weightn of sample}} \times 100 \quad \ldots.\ (12)$$

5. Colour

The dried grounded Beetroot slices was used to measure the color value by using a colorimeter (Konica minotta, Japan model-Meter CR-400). The equipment was calibrated against standard white tile and black tile. Around 20 g of dried beetroot slices powder was taken in the glass cup; the cup was placed on the aperture of the instrument. The colour was recorded in terms of L= lightness (100) to darkness (0); a = Redness (+60) to Greenness (-60); *b* = yellowness (+60) to blueness (-60).

6. Hardness

The texture of beetroot slices measured with texture analyser with force range 2500 N, speed range 1-500 mm/min with the speed-accuracy 0.1% (Make: M/s. Food Technology Corp. USA: Model:-). The above-mentioned beetroot slices of 4 mm were exposed to compression test with probe no-6, size 0.5 mm and pre-test speed was 60 mm/s, compression depth was 70 %, and trigger load was 5 g for beetroot slices. The equipment gives the value of hardness (N).

RESULTS AND DISCUSSION

Drying Kinetics

Fig. 2 shows the moisture content (%, db) of beetroot slices with respect to time (min) during solar drying. The beetroot slice was dried from an average initial moisture content of 650.750% (db) to 6.049±2% (db). It took around 33 h for drying of beetroot slices and 5 days by solar drying to complete the drying process. Initially the change in moisture content was rapid, and drying was faster, followed by slowing down of the changes. Similar behaviour had been observed by Pangavhne *et al*. (2002) during solar drying of grape leather.

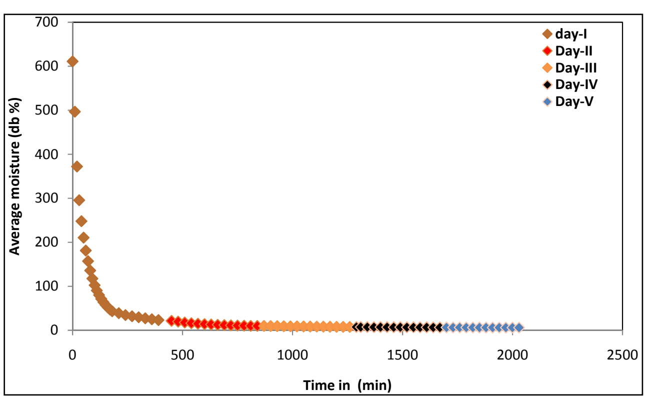

Fig. 2: Moisture content % (db) versus time (min) by solar drying

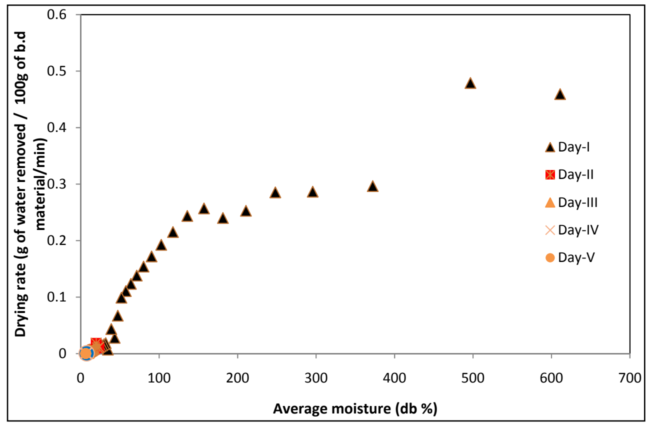

Fig. 3: Drying rate (g water removed/100 g of bone dry material/min) versus moisture content % (db) of beetroot slices dried by solar drying

Fig. 3 shows the drying rate (g water removed/100g of bone dry material/min) with respect to moisture content % (db) of beetroot slices dried by solar drying. The drying rate of beetroot slices were decreased from 0.459 g of water removed / 100 g of bone dry matter per minute to the 0.00014 g of water removed /100 g of bone dry matter per minute. At the beginning of the drying process, the drying rate was 0.459 g of water removed / 100 g of bone dry matter per minute, increased up to 0.4790 g of water removed / 100 g of bone dry matter per minute in first 20 min, and then started decreasing up to 0.00014 g of water removed / 100 g of bone dry matter per minute towards the end of drying.

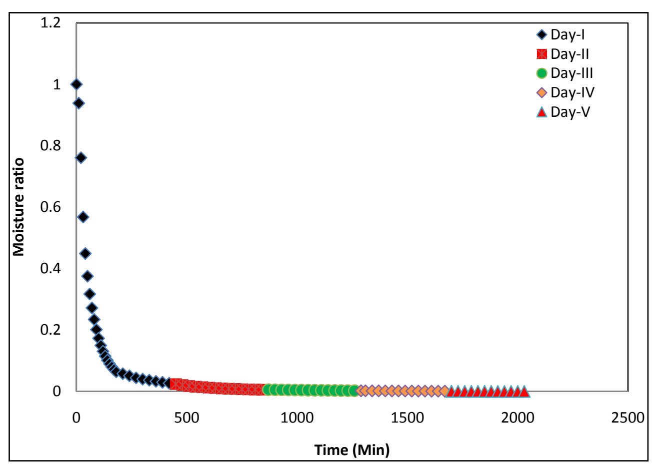

Fig. 4: Variation in moisture ratio with respect to time, min for beetroot slices during solar drying

Fig. 4 shows the variation in moisture ratio with respect to the time consumed for drying during 5 days of solar drying of beetroot slices. During the drying experiment moisture ratio decreased from 1 to 1.51 × 10^{-8} as the time of drying increases.

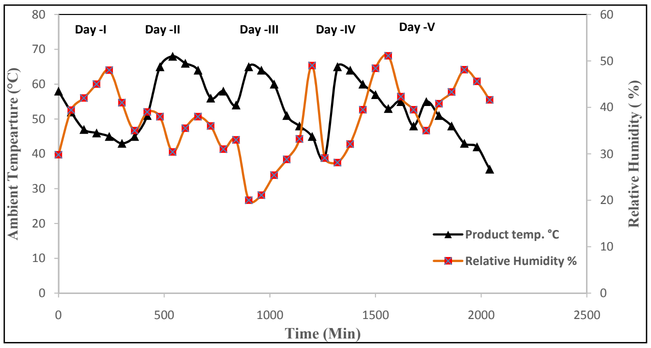

Fig. 5: Variation in ambient temperature and relative humidity with time in solar drying of beetroot slices

Fig. 5 shows that, change in the ambient temperature (°C)and relative humidity (%) with respect to the time during the 5 days of solar drying. The average relative humidity (%) for the ambient air inside the dryer was 45.25±5.41% and varied from 30.20 to 60.25%. Fig. 6 shows the variation in product temperature, ambient air temperature variations with respect to time during 5 days of drying of beetroot slices. The average product temperature was 31.4**°C**. The average ambient temperature was 38.56**°C**. The ambient air temperature was in the range 29.5-51.0°C. The product temperature varied from 19.4 to 49.56**°C**.

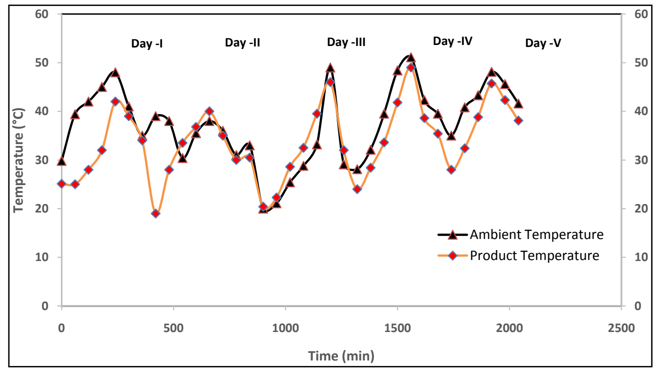

Fig. 6: Variation in product temperature and ambient air temperature with time

Evaluation of thin layer-drying model of beetroot slices

The Table 2 shows the model parameters of various model fitted to the experimental data for solar drying of beetroot slices. Newton model, Page model, Henderson and Pabis, Exponential, Modified page, Thompson, Logarithmic, modified page equation II etc. Among the models fitted to the experimental data for solar drying, the Henderson and Pabis model was well fitted to the experimental data with

Table 2: Model parameters, R^2, RMSE and Chi square values of beetroot slices dried by the Solar drying

Sl. No.	Model name	Model Parameters	R^2	MSE	Chi
1	Newton	k = 0.017580091	0.990860997	0.000402967	0.032237398
2	Page	k = 0.018077063 n = 0.993296787	0.990866917	0.000407804	0.032216514
3	Modified Page	k = 0.017594053 n = 0.993294937	0.990866917	0.000407804	0.032216514
4	Henderson and Pabis	a = 1.033472945 k = 0.018203838	0.991451648	0.000381695	0.030153905
5	Exponential	k = 0.017580091	0.990860997	0.000402967	0.032237398
6	Thompson	a = -1.00702E+02 b = -1.010577656	0.946039743	6.53753E+04	5.16465E+06
7	Logarithmic	a = -0.000000001 k = -0.007825144 c = 0.094151554	0.151593750	0.038368111	2.992712621
8	Modified Page equation-II	k = 3.992179642 L = 1.51339E+01 n = 0.993293310	0.990866917	0.000407804	0.032216514

r^2 = 0.991; MSE = 0.00038 and chi square (χ^2) = 0.0301. Linear regression analysis was done according to the six thin layer models for moisture ratio data. Table (3) shows the statistical regression results of the different models, including the drying model coefficients and comparison criteria used to evaluate goodness of the fit including the r^2, χ^2 and *RMSE* of beetroot slices at solar drying. In solar drying r^2 values for the model were equal to 0.991, indicating a good fit. The model parameter i.e., '*k*' = 0.018. The 'a' were 1.033. The Akpinar (2008) had reported that Wang and Singh model to fit well to the behavior of Parsley leaves dried under a solar dryer, Babalis *et al*. (2006) found the Two term exponential model well fitted to the solar drying of figs, Sacilik *et al*. (2006) found the Diffusion model well fitted to the solar tunnel drying of organic tomato.

Effective moisture diffusivity

Fig. 7 shows Ln(MR) versus time (minute) for solar drying of beetroot slices. The graph shows the straight line curve. The straight line equation $y = mx + cw$ here the m is the slope of line. Effective diffusivity (D_{eff}) at time for beetroot slices which was calculated by equation (4). Table (3) shows the effective diffusivity of beetroot slices dried at solar drying. The diffusivity value was 2.5315 × 10^{-8} m^2/s for the solar drying. The generally, effective diffusivity is used to explain the mechanism of moisture movement during drying and the complexity of the process (Kashaninejad *et al*. 2007; Falade and Solademi, 2010). The results indicated a linear relationship between (log D_{eff}) and ($1/T_{abs}$) as plotted in Fig. 7 for beetroot slices dried by solar drying. The diffusivity constant or pre- exponential factor of Arrhenius equation (D_0) calculated from the linear regression are 0.2320 m^2/s for beetroot slices Equation (13) shows the effect of temperature on effective diffusivity of beetroot slices.

$$D_{eff} = (0.2320)\exp.\left(\frac{Ea}{R(T+273.15)}\right) \qquad \ldots(13)$$

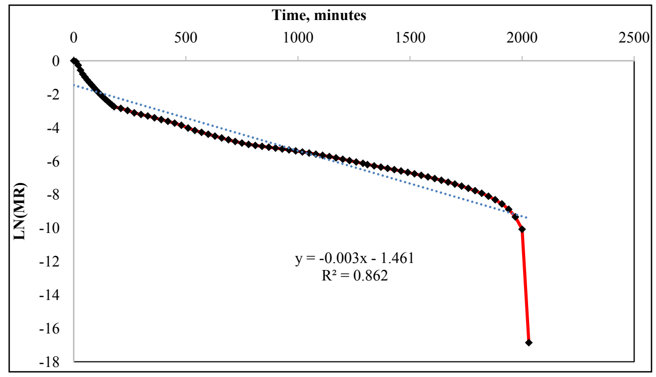

Fig. 7: Ln(MR) versus time, minutes for effective diffusivity for Solar drying of beetroot slices

Evaluation of quality parameters for the dried product

1. Moisture content

Table 4 shows the moisture content of beetroot fruit and slice powder before and after solar drying. Moisture content of fresh beetroot slices was 669.89±12.36% and it decreased up to 6.095±2 % after solar drying. It was observed from the data presented in Table 4 & 5 that the moisture content of beetroot was decreased significantly. The decreases in moisture content were significant at $p \leq 0.05$.

2. Total soluble solid

The total soluble solid of beetroot fruit and slice powder before and after solar drying. Total soluble solid of fresh beetroot slices was 10 ± 2.00 and Total soluble solid of solar dried beetroot slices was 57.33±0.58. The increases in total soluble solid of beetroot slices after solar drying might be attributed due to moisture inside the cell membrane started diffusing outward from surface to ambient and leaving behind solid content. With passage of drying time, most of the free water evaporated and only solid remained. The increase of total soluble solid was significant at $p \leq 0.05$. Abrol *et al.* (2014) reported that TSS of fresh banana was 23.20 ± 0.16°Brix and after drying at solar it found increased to 64.60 ± 0.16°Brix.

3. pH

The pH of beetroot fruit and slice powder before and after drying at different temperature. The pH of beetroot slices was 7.27±0.24 before drying and then after solar drying of beetroot slices with final pH as 6.57±0.15. The decrease of pH content was significant at p≤0.05. A similar kind of result has been observed by El-Beltagy, Gamea, and Amer-Essa (2005) reported that pH of fresh strawberries was 4.10, and after drying at solar, it found to decrease to 3.88.

4. Titratable Acidity

The titratable acidity of beetroot fruit and slice powder before and after solar drying. Titratable acidity of beetroot slices increases from 0.31 ± 0.21 to 1.28±0.13%. The increases in titratable acidity of beetroot slices after drying might be attributed due to rapid removal of water present in the slices as a result of an increase in temperature .The decrease of titratable acidity content was significant at p≤0.05. El-Beltagy, Gamea and Amer Essa., (2005) reported that titratable acidity of fresh strawberry was 0.52% and after drying at solar it found increased to 1.52 %; Abrol *et al.* (2014) reported that the titratable acidity of fresh banana was 0.125 ± 0.002% and after drying at solar it found increased to 0.990 ± 0.001%.

5. Reducing Sugar

The reducing sugar of beetroot fruit and slice powder before and after solar drying. The reducing sugar increases from 0.29 ± 0.03 to 2.93±0.23%. This increase in reducing sugar might be attributed due to the concentration of fruit flavours and calories during drying. The increase in reduced sugar content was significant at p≤0.05. Prajapati, Prabhat and Rathore (2011) reported that reducing sugar of fresh aonla was 1.9% and after drying at solar, it found increased to 3 %.

Table 4: Chemical composition of beetroot slices before and after drying

Sl. No.	Chemical constituents	Before drying	After drying
1	(a) Moisture %db	669.89 ±8.25	6.095±2
2	(b) T.S.S °B	10 ± 2.00	57.33±0.58
3	(c) pH	7.27 ± 0.15	6.57±0.15
4	(d) Titratable acidity %	0.31 ± 0.21	1.28±0.13
5	(e) Reducing sugar %	0.29 ± 0.03	2.93±0.23
6	(f) Total Sugar %	18.80 ± 0.56	41.48±1.08
7	(g) Hardness N	—	56.84±0.00
8	(h) Colour		
	L	33.69±0.12	26.108±0.12
	a	31.50 ± 0.85	28.78±0.12
	b	9.10 ± 0.16	13.636± 0.06

**values are non-significant at p≤0.05.*

6. Total Sugar

The total sugar of beetroot fruit and slice powder before and after drying at solar dryer. The data reveals that the per cent total sugar content of beetroot powder increase from 18.80 ± 0.56 to 41.48 ± 1.08 %. The increase of total sugar content was significant at p≤0.05. Abrol *et al.* (2014) reported that total sugar of fresh banana was 19.22% and after drying at solar it found increased to 45.96%.

Table 5: ANOVA Table

Sl. No.	Parameter	Moisture	T.S.S	Acidity	Total sugar	Reducing sugar	pH	Colour		
								L	a	b
1	$S.E_m$ (5%)		0.33	0.07	0.81	0.14	0.09	0.33	0.07	0.06
2	C.D (5%)		4.68	1.04	8.79	1.90	1.24	4.70	0.92	0.04
3	S.D		2.03	0.45	3.81	0.82	0.54	2.04	0.40	0.01
4	D.f (Bet- group)	3	3	3	3	3	3	3	3	3

7. Hardness

The hardness of beetroot slices at solar drying. Hardness of beetroot slices were observed was 56.84 ± 0.00 (N). The textural properties of dehydrated products are normally measured as puncture force, which is measure of hardness of products surface and is an indicator of extend of case hardening that has occurred during drying (Lin *et al*. 1998). The increase of hardness of beetroot slices was non-significant at p≤0.05.

8. Colour

The colour of beetroot fruit and slice powder before and after drying at solar dryer. The L value of beetroot slices was 33.69 ± 0.12 after solar drying it decreases up to *26.108 ± 0.12.* The decrease of colour pigment was significant at p≤0.05. Similarly before drying a was 31.50 ± 0.85 and after drying it decreases up to 28.78 ± 0.12. Also for b value of beetroot slices was 9.10 ± 0.16 and after drying it increases up to 13.636 ± 0.06. This variation in colour is due to pigment degradation because of long drying duration.

CONCLUSION

1. Solar drying of beetroot slices reduces the moisture from 611.019–6.096 % (db) had taken 33 hr for drying and 5 days to complete drying process.
2. The drying rate of beetroot slices at solar dryer were decreased from 0.459 g of water removed / 100 g of bone dry matter per minute to the 0.00014 g of water removed /100 g of bone dry matter per minute.
3. Among the models fitted to the experimental data to solar drying, the Henderson and Pabis model was well fitted to the experimental data with $r^2 = 0.9914$; $MSE = 0.00038$ and chi square (χ^2) = 0.0301.
4. Effective Diffusivity (D_{eff}) at time (t) for Beetroot slices drying by Solar drying was 2.53154×10^{-8} m^2/s.
5. From the above results it can be concluded that solar drying technique was an effective treatment to beetroot slices (4 mm) as it reduces the final drying time and improved the quality of dried sample.
6. There are significantly increase in the total soluble solid, there are decrease in the titratable acidity of beetroot. The reducing sugar increases, also increase in total sugar, hardness increases, also there are decrease in colour values *L, a, b*, after drying at solar dryer at the p≤0.05.

NOMENCLATURE

MR	Moisture Ratio
a, b, c, g, k, n and l	Constant
t	Time, min
M	Moisture Content at time t, % db
M_e	Equilibrium Moisture Content, % db
M_0	Initial Moisture Content, % db
r	Co-relation Coefficient
RMSE	Root Mean Square Error
MR_{exp}	Experimental Moisture Ratio
MR_{pre}	Predicted Moisture Ratio
D_{eff}	Effective diffusivities, m^2/s
R^2	Radius, m

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