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Research paper

Open Sun Drying of Beetroot Slices and its Quality Evaluation

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ABSTRACT

Drying characteristics of beetroot slices was investigated by open air sun drying method of 4 mm thickness beetroot slices, beetroot slices dried from 650.750 % (db) moisture content to 7.035 % (db) in open air sun dryer in 50 hr. Seven drying model fitted to experimental data i.e. Newton model, Page model, Exponential, Modified page, Thompson, Midilli, modified page equation II etc. Among the models fitted to the experimental data to open sun drying, the Midilli drying model was well fitted to the experimental data with $r^2 = 0.9896$; MSE = 0.00036 and chi square (χ^2) = 0.0414 to experimental moisture ratio with respect to time. Effective Diffusivity (D_{eff}) at time (t) for Beetroot slices drying by open air sundrying was 1.62278×10^{-8} m²/s. Variation in ambient air temperature was in the range 29 - 51.7°C, The product temperature varied from 20 to 49.4**°C** and the average relative humidity (%) for the ambient air inside the dryer was 48.64±10.21%, and varied from 30 to 65%. Effect of quality parameter i.e. acidity, TSS, pH, reducing sugar, total sugar, moisture, hardness and colour (L, a and b value) on fresh beetroot slices and dried beetroot slices after drying at open air sun drying were determined and discussed at p≤0.05. Total soluble solid of fresh beetroot slices was 10 ± 2.00 °B and open air sun drying total soluble solid content beetroot slices was 58.33±0.58 °B, the pH of beetroot slices before drying was 7.27±0.24 and then after open air sun drying pH of beetroot slices was 5.83±0.25, titratable acidity of beetroot slices before drying was 0.31 ± 0.21 % and it increases up to 0.83±0.14 %, the reducing sugar content of beetroot slices before drying was 0.29±0.03 % and then after open air sun drying reducing sugar content of beetroot slices was 3.12±0.14 %, the total sugar content of beetroot slices before drying was 18.80±0.56 % and then after open air sun drying total sugar content of beetroot slices was 42.01±0.62%, 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 open air sun drying L, a, b value of beetroot slices was 34.37±0.46, 23.66±0.07 and 16.19±0.002 respectively.

Keywords: Open air sun drying, moisture ratio, drying behaviour, drying models, effective diffusivity (D_{eff}), and quality evaluation

Beetroot (*Beta vulgaris L.*) is botanically classified as an herbaceous biennial from chenopodiaceae family and has several varieties with bulb colours ranging from yellow to red (Singh and Hatan, 2014). 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 vegetable with respect to antioxidant capacity described to total phenolic content of 50-60 µmol/dry weight (Singh and Hatan 2014; Vinson *et al.* 1998). The plant consists of roots and 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, known as beetroot red (Ninfali and Angelina, 2013).

Beetroot are rich in valuable, active compounds such as carotenoids (Dias *et al.* 2005), betacyanines (Patkai, 1997), folates (Jastrabova *et al*. 2003), betanin,

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polyphenols and flavonoides (Vali *et al.* 2007). Therefore beetroot ingestion can be considered a factor in cancer prevention (Kapadia *et al*. 1996).

Beetroot is popularly consumed as red food colorants, e.g. to improve colour of tomato paste, sauces, dessert, jam and jellies, ice-cream, sweet 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, significant amount of vitamin C and vitamin B1 , B2, niacin, B6, B12 (Singh *et al*. 2013). Juice of beetroot is also consumed as a natural remedy for sexual weakness and to expel the kidney and blades stone (Sharma *et al.* 2014). Extract of root posses antihypertensive, hypoglycaemic, antioxidant (Ninfali *et al*. 2013), anti-inflammatory and hepato-proctective 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 is potential herb used in cardiovascular condition (Vali *et al*. 2007). Beetroot is an excellent source of foliate 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 of traditional snacks that are rich in Tran’s fatty acid (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 colour of beetroot is owing to a group of red pigments known as betalains. Betalains are antioxidants and having profound health benefits.

Food drying by sun is one of the oldest methods of preserving food for later use. It is complex operation involving heat and mass transfer which may cause change in food quality. Open-air sin drying is most commonly used method to preserve agricultural products like grains, fruits and vegetables in most developing countries (Pangavhane *et al.* 2002). In open sun drying (OSD), the crop is spread in thin layer on the ground and exposed directly to the open air sun radiation, wind and other condition (Jain and Tiwari, 2003). In OSD, the open air sun radiation falling on the crop surface is partly reflected and partlyabsorbed. Part of this heat propagates to the interior of the crop causing a rise in the temperature and formation of water vapour and remaining amount is utilized in evaporation of moisture from the surface. The moisture from the interior diffuses to the surface to replenish the evaporated surface moisture (Hande *et al.* 2016).

Drying process reduces the content of moisture and then chemical alteration help in minimizing microbiological activity in the product during the storage. Therefore the persistence of the product and its stability will increase. Dehydration improves the food stability, since it reduces considerably the water and microbiological activity of the material and minimizes physical and chemical changes during its storage, reduce spoilage, increase shelf life, reduction products 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 intensiveprocess 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 the fruits and vegetables by Open-air sun drying. Bechoff *et al*. (2009) studied the effect of hot air, open air sun and solar drying on pro vitamin (A) retention in Orange fleshed sweet potato; Tunde- Akintunde *et al*. (2005) studied the influence of drying methods i.e. sun, open air sun and artificial air drying on drying of bell- pepper; Jain and Tiwari (2003) studied the thermal aspects of open sun drying o various crops; Akpinar *et al.* (2003) studied the thin layer drying of red pepper; Arslan and Ozcan (2010) studied the effect of the sun, oven and microwave drying on quality on onion slice; Chong *et al.* (2009) studied the drying model and quality analysis of sun dried ciku; Mahmutoglu *et al.* (1996) studied the sun / open air sun drying of differently treated grapes and storage stability of dried grapes and Muskan *et al.* (2002) studied the hot air and sun drying of grape leather (pestil).

No reports are available so far for drying of beetroot slices by open air sun 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 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, also the unwanted parts like leafed and stalk material were removed. After surface moisture removal the tubers were peeled by using hand peeler. The peeled tubers were sliced into 4 mm thickness.

Experimental setup for Open Sun drying

Firstly the floor surface where open sun drying carried out is cleaned. The perforated trays of 81×41×3.4 cm in length, width and height respectively were mounted on 2.5 ″ bricks. The trays were kept in sun light at 10 cm height above the ground surface for cross-flow air drying and the care was taken that the product should get sun light availability throughout the whole day. The sugar beets are sliced at 4 mm thickness and were placed on the perforated trays of 1×1 mm mesh size for open drying. The observations were recorded i.e. product temperature, ambient air temperature, relative humidity etc. The samples were dried and also the weight loss of each sample were recorded at regular interval for 10 min for first 3 h and then after 30 min at each till the constant weight was achieved by using electronic weighing balance yet this reaches to constant weight and drying characteristics were studied. The longitude for Roha was .....N-S and Latitude for Roha was ....N-S. The experiment was triplicated for each treatment and corresponding drying characteristics were studied.

Measurements

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).

$$\text{Moisture content (db) \%} = \frac{W_1 - W_2}{W_2} \times 100 \qquad \text{... (1)}$$

Where,

W_1 = Weight of sample before drying, *g*

W_2 = Weight of sample after drying, *g*

Open sun dryer parameter measurement

Humidity and ambient air temperature was measured using a digital thermo-hygrometer (Make: Crystal instruments, 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 6 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 open sun 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 open sun 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 wet basis using following formula (Chakraverty, 2003). The moisture ratio usually expressed as-

$$\text{Moisture ratio (MR)} = \frac{M - M_e}{M_o - M_e} \quad \ldots (2)$$

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).

$$R = \frac{W_r}{T \times W_d} \times 100 \quad \ldots(3)$$

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.

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

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).

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 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:

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

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.

Effective moisture diffusivity and activation energy

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

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

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:

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

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:

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

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:

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

Where,

L= half thickness

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	Modified Page equation-II	MR = a.exp (-kt)^n	Zhang and Litchfield, 1991
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	Midilli *et al.*	MR = a.exp (-kt^n) + bt	Midilli *et al.* 2002

Evaluation of Quality parameters for the beetroot powder Product

1. Total soluble solids

Total soluble solids was determined for fresh beetroot slices and dried after open sun drying by using Refractometer (M/s. Atago, Japan) and the values were corrected at 20°C. The equipment was calibrated with distilled water and the TSS of the beetroot juice before drying and slices powder after drying was determined by adding the 5 g sample in to 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 open air sun drying was measured using digital pH meter. The digital pH meter is firstly 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 was then submerge in to the sample. The pH reading display on the primary LCD and temperature on secondary one. The pH of fresh beetroot slices and slices after open air sun drying was determined by three replication.

3. Titratable acidity

The titratable acidity of beetroot juice and slice powder after drying at open air sun 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.

$$\text{Titratable acidity (\%)} = \frac{N \times T \times E}{W \times V \times 1000} \times 100 \quad \ldots(12)$$

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 open air sun drying estimated by using Lane and Eynon Method with modifications suggested by Ranganna (1997). A known weight of beetroot slices were crushed with distilled water using lead acetate (45%) 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 end point. The three replication were carried out and the average reading was reported.

Reducing sugar % =

$$\frac{100}{\text{Burettereading}} \times \frac{\text{Volume prepared}}{\text{Inital volume}} \times GV \text{ of fehling's solution} \quad \ldots(13)$$

Where,

GV = Glucose value

4. Total sugars

Total sugars was estimated was for beetroot juice and slice powder after drying at open air sun 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. 14). The experiment was repeated three times to get the replication.

Total sugar (%) =

$$\frac{\text{Factor} \times \text{Dilution}}{\text{Titrereading} \times \text{Weightn of sample}} \quad \ldots(14)$$

5. Colour

The dried grounded Beetroot slices was used to measure the colour value by using colorimeter (Konica minotta, Japan model-Meter CR-400). The equipment was calibrated against standard white tile and black tile. Around 20 g 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

Fig. 1 shows change in moisture content (%, db) with respect to time (min) of beetroot slices dried by open sun drying. The beetroot slice was dried from an average initial moisture content of 650.750% (db) to 7.035 % (db). It took around 50 h for drying of beetroot slices and 7 days by open sun 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 for onion slices and parsley leaves (Arslan and Ozcan M., 2010; Akpinar., 2008).

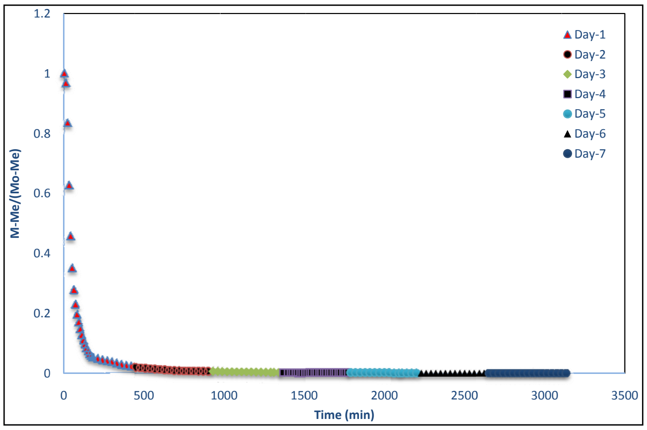

Fig. 1: Moisture content %(db) versus time (min) open air sun drying for beetroot slices

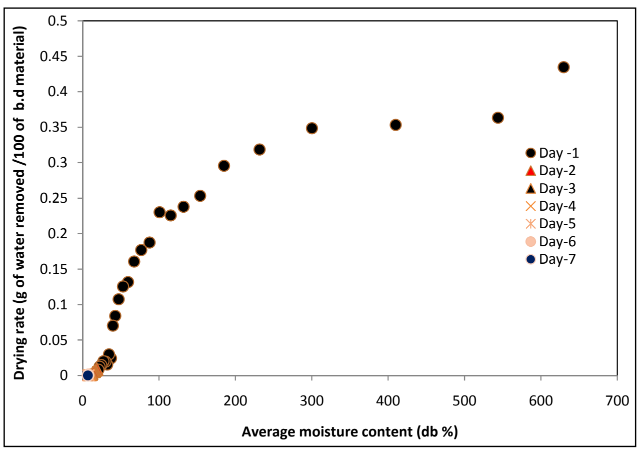

Fig. 2: Drying rate (g water removed/100 g of bone dry material/min) versus moisture content % (db) of beetroot slices dried by open sun drying

Fig. 2 shows the drying rate (g of water removed/100g of bone dry material /min) with respect to moisture content % (db) of beetroot slices dried by open sun drying. The drying rate of beetroot slices were decreased from 0.434 g of water removed / 100 g of bone dry material per minute to the 1.59×10^{-4} g of water removed /100 g of bone dry material per minute. Drying took place in falling rate periods.

Fig. 3 shows variation in moisture ratio with respect to the time consumed for drying during 7 days of open sun drying of beetroot slices. During the drying experiment moisture ratio decreases from 1 to 3.07×10^{-8} as the time of drying increased. The similar curve was observed for prickly pear, grapes, frappe leather, kokum and naggets by the scientist Lahasani *et al.* (2002), Mahmutoglu *et al.* (1996), Muskan *et al.* (2002), Mishra *et al.* (2006) and Swami *et al.* (2006).

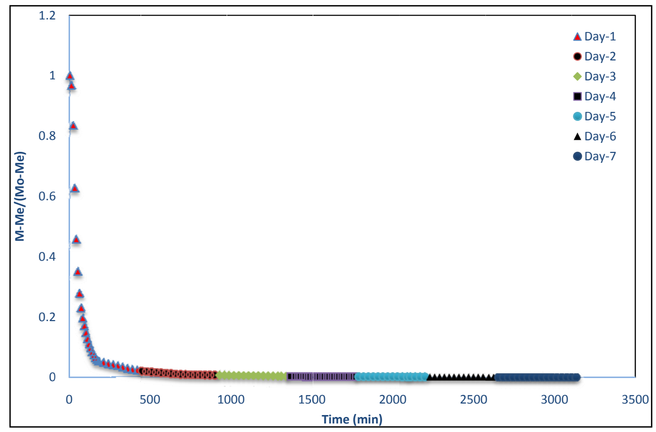

Fig. 3: Variation in moisture ratio with respect to time, min for beetroot slices during open air sun drying

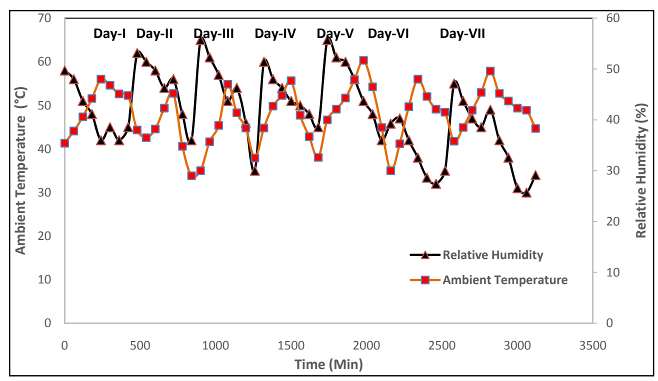

Fig. 4: Variation in ambient temperature and relative humidity with time in open air sun drying of beetroot slices

Fig. 4 shows the change in the ambient temperature (°C) and relative humidity (%) with respect to the time during the 7 days of open sun drying. The product temperature ranges from 20 to 49.4°C and relative humidity ranges from 30 to 65 %.

Fig. 5 shows the variation in product temperature, ambient air temperature variations with respect to time during 7 days of drying of beetroot slices. The average product temperature was 35.67°C. The average ambient temperature was 40.98°C. The ambient air temperature was in the range 29 -51.7°C. The product temperature ranges from 20 to 49.4°C.

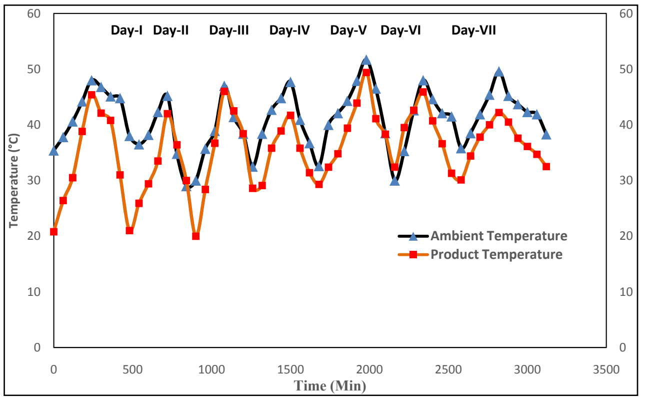

Fig. 5: Variation in product temperature and ambient air temperature with time

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 open drying of beetroot slices. Newton model, Page model, Exponential, Modified page, Thompson, Midilli, Modified page equation II etc. Among the models fitted to the experimental data to open sun drying, the Midilli drying model was well fitted to the experimental data with $r^2 = 0.9896$; MSE = 0.00036 and chi square $\chi^2 = 0.0414$. Non-linear regression analysis was done according to the seven thin layer models for moisture ratio data. Table (2) 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 open sun drying. In open sun drying case r^2 values for the model were equal to 0.9896 indicating a good fit. The model parameters like *a* and *k* are the characteristics constant, *k* is diffusivity (diffusion coefficient and it is temperature dependent). The model parameter i.e. $a = 1.061$, $k = 0.0122$, $n = 1.115$ and $b = 1.096 \times 10^{-6}$. The Akpinar (2008) had found Wang and Singh model to fit well to the behaviour of Parsley leaves dried under open sun drying, Babalis *et al*. (2006) found the Two term exponential model well fitted to the open air sun drying of figs, Sacilik *et al*. (2006) found the Diffusion model well fitted to the open air sun tunnel drying of organic tomato.

Effective moisture diffusivity

Fig. 6 shows Ln(MR) versus time (minute) for open air sun drying of beetroot slices. The graph shows

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

Sl. No.	Model name	Model Parameters	R^2	MSE	Chi
1	Newton	$k = 0.018408098$	0.983340732	0.000518222	0.060631932
2	Page	$k = 0.008294005$ $n = 1.195598002$	0.987035107	0.000406777	0.047186140
3	Modified Page	$k = 0.018165633$ $n = 1.195592709$	0.987035107	0.000406777	0.047186140
4	Exponential	$k = 0.018408098$	0.983340732	0.000518222	0.060631932
5	Thompson	$a = -1.00714E+02$ $b = 1.863567256$	0.941024044	1.76822E+05	2.05113E+07
6	Midilli *et al.*	$a = 1.061916692$ $k = 0.012259725$ $n = 1.115431849$ $b = 0.000001096$	0.988619447	0.000363332	0.041419882
7	Modified Page equation-II	$k = 9.167739670$ $L = 1.87409E+01$ $n = 1.195605914$	0.987035107	0.000406777	0.047186140

the straight line curve. The straight line equation $y = mx + c$ where the m is the slope of line. Effective diffusivity (D_{eff}) at time for beetroot slices which was calculated by equation (9). Effective Diffusivity (D_{eff}) at time (t) for Beetroot slices drying by Open air sun drying was 1.62278×10^{-8} m^2/s. The generally, effective diffusivity is used due to explain the mechanism of moisture movement during drying and complexity of the process (Kashaninejad *et al*. 2007; Falade and Solademi, 2010). Similar kind of results have been observed for sweet potato slices ranged from 1.25×10^{-10} m^2/s to 1.68×10^{-9} m^2/s and 2.28×10^{-10} m^2/s to 9.75×10^{-9} m^2/s for first and second falling rates respectively (Falade and Solademi, 2010), also this values lie within the general range of 10^{-11} to10^{-6} m^2/s reported by Zogas *et al*. (1996) and Marinos-Kourisand Maroulis (1995) for the food material.

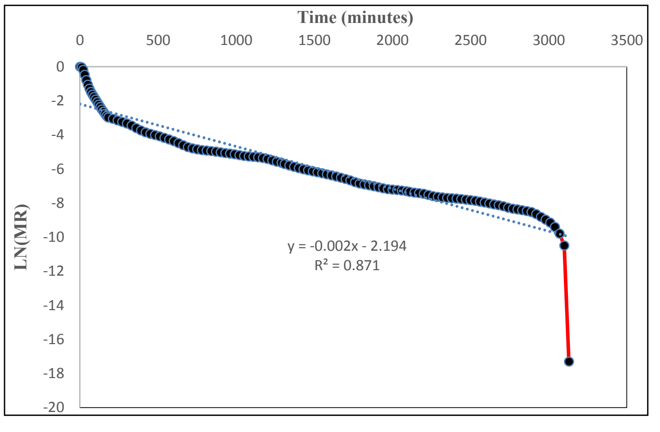

Fig. 6: LN(MR) versus time, min for effective diffusivity of sun dried beetroot slices

The diffusivity constant or pre- exponential factor of Arrhenius equation (D_0) calculated from the linear regression are 0.11147 m^2/s for beetroot slices Equation (10) shows the effect of temperature on effective diffusivity of beetroot slices.

$$D_{eff} = (0.11147)\exp.\left(\frac{E_\alpha}{R(T+273.15)}\right)$$

Evaluation of quality parameters for the dried product

1. Moisture content

Table 4(a) shows the moisture content of beetroot slices and slice powder before and after open air sun drying. Moisture content of fresh beetroot slices was 650.750±12.36% (db) and it decreases from 7.035±1.025% (db) after drying respectively. It is observed from the data presented in Table 4 and 5 that the moisture content of beetroot was decreases significantly. The decreases of moisture content were significant at $p \leq 0.05$.

2. Total soluble solid

Table 4(b) shows the total soluble solid of beetroot slices and slice powder before and after drying. Total soluble solid of fresh beetroot slices was 10 ± 2.00 °B and it increases up to 58.33±0.58°B at open air sun drying. The increases in total soluble solid of beetroot slices after open air sun 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 free water evaporated and only solid remained. The increase of total soluble solid was significant at $p \leq 0.05$.

3. pH

Table 3 (c) shows the pH of beetroot slices was 7.27±0.15 before drying and then after drying of beetroot slices with final pH as 5.83±0.25. The decrease in pH content was significant at $p \leq 0.05$. Hande *et al.* (2016), found the pH of fresh kokum rind was 2.54 and after open air sun drying it was 2.50.

4. Titratable acidity

Table 4(d) shows the chemical composition of beetroot slices and slice powder before and after drying. Acidity of beetroot slices before drying was 0.31 ± 0.21 and then after open air sun drying the titratable acidity was 0.83±0.14%. The increases in acidity of beetroot slices after drying might be attributed due to rapid removal of water present in the slices as a result of variation in temperature. The increase of acidity content was significant at $p \leq 0.05$.

5. Reducing Sugar

Table 4 (e) shows the reducing sugar of beetroot slices and slice powder before and after at open air sun drying. The reducing sugar increases from 0.29±0.003 to 3.12±0.14%. This increase in reducing sugar might be attributed due to concentration of fruit flavours and mass/solids during drying. The increase of reducing sugar content was significant at p≤0.05.

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

Sl. No.	Chemical constituents	Before drying	After drying
(a)	Moisture %db	669.89 ±3.12	7.049±0.24
(b)	TSS °B	10 ± 2.00	58.33±0.58
(c)	pH	7.27 ± 0.15	5.83±0.25
(d)	Titratable acidity %	0.31 ± 0.21	0.83±0.14
(e)	Reducing sugar %	0.29 ± 0.03	3.12±0.14
(f)	Total Sugar %	18.80 ± 0.56	42.01±0.62
(g)	Hardness N	—	36.848±0.00
(h)	Colour L	33.69±0.12	34.37 ± 0.46
	(a)	31.50 ± 0.85	23.66 ± 0.07
	(b)	9.10 ± 0.16	16.19 ± 0.02

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

6. Total Sugar

Table 4 (f) shows the total sugar of beetroot slices and slice powder before and after open air sun drying. The data with respect to the total sugars of beetroot powder presented in Table 5. The data reveals that the per cent total sugar content of beetroot powder was 42.01±0.62. The increase of total sugar content was significant at p≤0.05. Pragati *et al.* (2003) reported that total sugar content was 26.53% during open air sun drying of aonla fruits.

7. Hardness

Table 4(g), shows the hardness of beetroot slices at open sun drying. Hardness of beetroot slices was observed 36.848(N).

8. Colour

Table 4 (h) shows the colour of beetroot slices and slice powder before and after drying different temperature. The L value of beetroot slices was 33.69±0.12 after drying at open air sun it increases up to 34.37± 0.46. The decrease of colour pigment was significant at p≤0.05. Similarly before drying was 31.50±0.85 and after drying it decreases up to 23.66 ± 0.07. Also for b value of beetroot slices was 9.10±0.16 and after drying it decreases up to 16.19 ± 0.02. This variation in colour is due to pigment degradation because of long drying duration.

CONCLUSION

1. Open air sun drying of beetroot slices reduces the moisture from the 650.750–6.049 % (db) had taken the 50 h to dry and 7 days to complete the drying process.
2. The drying rate of beetroot slices were decreased from 0.434 g of water removed / 100 g of bone dry matter per minute to the 1.59×10^{-4} g of water removed /100 g of bone dry matter per minute.
3. Among the models fitted to the experimental data to open sun drying, the Midilli drying model was well fitted to the experimental data with $r^2 = 0.9896$; $MSE = 0.00036$ and chi-square $(\chi^2) = 0.0414$.
4. Effective Diffusivity (D_{eff}) at time (t) for Beetroot slices drying by Open air sun drying was 1.62278×10^{-8} m²/s.

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	0.08	0.36	0.08	0.15	0.26	0.04	0.01
2	C.D (5%)		2.03	0.49	2.18	0.49	0.88	1.60	0.25	0.08
3	D.f (Bet-group)	3	3	3	3	3	3	3	3	3

5. There are significantly increase in the total soluble solid, the reducing sugar, total sugar, and hardness. Decrease in the titratable acidity of beetroot and decrease in colour values L, a, b, after drying at open air sun drying are significant at the p≤0.01.

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, m2/s
R^2	Radius, m

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