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Research Paper

Studies on Drying characteristics of Beetroot Slices at varied Temperatures and Its Quality Evaluation

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ABSTRACT

Drying characteristics of beetroot slices was investigated by convective hot air drying method at the temperature 40°C, 50°C, 60°C and 70°C of 4 mm thickness beetroot slices. Beetroot has the many medicinal, pharmaceutical, nutraceutical applications. Five drying model i.e. Newton, Page, Modified Page, Thompson, Modified Page Equation II were fitted to the experimental data on moisture ratio with respect to time. Modified Page Equation II drying model best fitted with $r^2 \geq 0.9691$; MSE ≤ 0.000840; $\chi^2 \geq 0.1015$ to experimental moisture ratio with respect to time. Effective moisture diffusivity for beetroot slices dried at different temperature was 2.10962×10^{-9} m²/s, 5.03063×10^{-9} m²/s, 1.03858×10^{-8} m²/s, 1.34691×10^{-8} m²/s at 40°C, 50°C, 60°C and 70°C respectively. The activation energy (E_a) for moisture diffusion was found to be 0.8160 kJ/mole. 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 40°C, 50°C, 60°C and 70°C respectively were also determined and discussed.

Keywords: Convective drying, moisture ratio, drying behaviour, 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 chenopodiaceae family and has several varieties with bulb colours ranging from yellow to red (Singh *et al.* 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 (Kahkonen *et al.* 1999; 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.* 2009), betacyanines (Patkai., 1997), folates (Jastrabova *et al.* 2003), betanin, 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

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health benefits, in particular for its disease fighting antioxidant potential, 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 blades stone (Sharma *et al*. 2014). Extract of root posses antihypertensive, hypoglycaemic, antioxidant (Ninfali and Angelina, 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.

Fresh beetroot contains high moisture content (85 % wb) and is very susceptible to deterioration due to lack of adequate preservation techniques. Convective hot air drying in hot air is still the most popular method applied to reduce the moisture content of the fruits and vegetable (Lewicki, 2006), including beetroots (Kaminski *et al*. 2014); Shynkaryk *et al*. 2008). Convection drying as well as other techniques for drying is used in order to preserve the original characteristics of foods.

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 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 the fruits and vegetables by using convective hot air dryer for carrots, white mulberry, okra, tomatoes, sweet potato cubes, azarole red and yellow fruit, kale, sweet cherry, figs, kiwifruits, uryani plum, red pepper, bay leaves, red bell paper, single apricots apple, anola shreds, potato, cape gooseberry, peach slices, sweet potato slices (Doymaz for 2004 a, 2004 b, 2005, 2007; Singh and Pandey 2012; Koylincu *et al*. 2007; Mwithiga and Olwal 2005; Doymaz and Ismail., 2011; Bablis *et al*. 2006; Orikasa *et al*. 2008; Sacilik *et al*. 2006; Doymaz and Pala 2002; Akpinar *et al*. 2003; Gunhan *et al*. 2005; Vega *et al*. 2007; Torgul and Pehliran, 2003; Sacilik and Elicin , 2006; Prapajapati *et al*. 2011 ; Nema and Dutta , 2004; Vasqvez-parva *et al*. 2013; Zhu and Shen, 2014; Fan *et al*. 2015). No reports are available so far for drying of beetroot slices by convective hot air 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 (APMC), 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 thickness.

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*

Experimental setup for tray drying

Tray drying of beetroot slices was performed at Department of Post Harvest Engineering, Post Graduate Institute of Post Harvest Management, Killa-Roha. The drying was carried out in the tray dryer (Make M/s. Aditi Associates, India; Model:ATD-124) having capacity of 5 kW. There were nine numbers of trays inside the trays dryer. The size of the tray was 81 cm × 41 cm × 3.4 cm the beetroot slices were dried in thin layer drying. The slices were spread on the tray in single layer. The mesh (square) size of the tray was 1x1 mm. The temperature of the drying was 40°C, 50°C, 60°C and 70°C. The air velocity inside the dryer was 2-3 m/s. The weight loss with respect to the time was recorded from trays at different location in the tray dryer. The moisture content with respect to the time was calculated from drying data. The drying data includes initial moisture content; weight loss, average moisture content with respect the time, drying rates, moisture ratios, and final moisture content of the beetroot slices were also are recorded. Three replication were taken for each experiment. Fig.1 shows the drying of beetroot slices.

Fig. 1: Drying of beetroot slices in tray dryer & weight loss was recorded by using small perforated trays

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 tray 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 tray 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 dry basis using following formula (Chakraverty, 2003).

$$\text{Moisture ratio} = \frac{M - M_e}{M_o - M_e} \qquad \text{...(2)}$$

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).

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

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.

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

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 (4). The higher the r^2 value and lower the chi-square (χ^2) equation (5) and lower value of *RMSE* values, the better is the goodness of fit (Ozdemir, Ozdemir & Devers., 1999; Ertekin & Yaldiz., 2004; Wang *et al*. 2007 a). According to Wang *et al* (2007 a) reduced chi-square (χ^2) and root mean square error (*RMSE*) can be calculated as follows:

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

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.

The non-linear regression analysis was performed by using the statistical software SAS 6.5.

Effective moisture diffusivity and activation Energy

The effective moisture diffusivity was 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:

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

Where,

L = half thickness

Determination of Effective Moisture Diffusivity and Activation Energy

The effective moisture diffusivity of the samples was estimated by using the simplified mathematical Fick's second diffusion model (Equation 7). The activation energy of the samples was obtained by plotting the natural logarithm of D_{eff} against the reciprocal of absolute temperature, then determining the slope of the straight line by using Equation (9). Activation energy was obtained by plotting the natural logarithm of D_{eff} against the reciprocal absolute temperature. Lopez *et al*. (2000) and Simal *et al.* (1996) related temperature with Arrhenius expression as:

$$D_{eff} = D_o.\exp.\left(\frac{-E_a}{R(T+273.15)}\right) \qquad \ldots(10)$$

Where,

Do = is the pre-exponential factor of the Arrhenius equation, (m^2/s)

Ea = is the activation energy (kJ/mol)

T = is the temperature of air, (°C)

R = is the universal gas constant, (8.134kJ/mol·K),

Rearranging Equation (10) gives Equation (11):

$$InD_{eff} = InD_o - \frac{E_a}{R(T+273.15)} \qquad \ldots(11)$$

Energy of activation can thus be calculated from Equation (11), which gives a relationship between temperature and effective moisture diffusivity. The plot of versus 1/(T+273.15) gives a straight line (slope of $K_L = E_a/R$). Linear regression analyses were used to fit the equation to the experimental data to obtain the coefficient of determination (r^2).

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 eq^n	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	Saciliket *al.* 2006

Evaluation of Quality parameters for the beetroot powder Product

1. Total soluble solids

Total soluble solids was determined for fresh beetroot slices and after drying at 40°C, 50°C, 60°C and 70°C 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 beetroot slices and after drying at 40°C, 50°C, 60°C and 70°C 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 40°C, 50°C, 60°C and 70°C was determined by three replication.

3. Titratable acidity

The titratable acidity of beetroot juice and slice powder after drying at 40°C, 50°C, 60°C and 70°C was determined as per procedure reported in 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 replication 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 40°C, 50°C, 60°C and 70°C 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.

$$Reducing\ sugar\ \% = \frac{100}{burette\ reading} \times \frac{volume\ prepared}{inital\ volume} \times GV of\ fehling's\ solution \quad \ldots(13)$$

Where,

GV = Glucose value

4. Total sugars

Total sugars was estimated was for beetroot juice and slice powder after drying at 40°C, 50°C, 60°C and 70°C 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.

$$Total\ sugar\ (\%) = \frac{Factor \times Dilution}{Titre\ reading \times Weightn\ of\ sample} \times 100 \quad \ldots(14)$$

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). 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).

SENSORY EVALUATION

The dried beetroot sample at 40°C, 50°C, 60°C and 70°C were subjected to sensory evaluation using a twenty member panellist consisting of staff and student of department of Post Harvest Engineering, Killa-Roha. The organoleptic qualities evaluated were taste, flavour, colour, texture and overall acceptability. The beetroot sample were served in clear glasses to individual panellist. The order of presentation of samples to the panel was randomized, drinking water was provided to rinse the mouth between evaluations to avoid the transfer of sensory attributes from one sample to other. Each sensory attribute was scored on a 9-point Hedonic Scale which ranged from 9-1 (liked extremely and disliked extremely) respectively according to the method of Iwe (2010).

RESULTS AND DISCUSSION

Drying Kinetics

Fig. 2 shows moisture content (db) % with respect to time (min) of beetroot slices dried by convective hot air dryer. The beetroot slices were dried from average initial moisture content of 650.750% (db) to 8.284% (db) at 40°C; 650.750% (db) to 11.297% (db). at 50°C; 650.750% (db) to 7.180% (db) at 60°C and 650.750% (db) to 6.822% (db) at 70°C respectively. It took around 53 h, 38 h, 24 h and 19 h time to dry the product at 40°C, 50°C, 60°C and 70°C respectively, as the temperature increases drying took place in falling rate periods. Fig. 3 shows the drying rate (g water removed/100 g of bone dry material; /min) with respect to moisture content % (db) of beetroot slices dried by tray drying at 40°C, 50°C, 60°C and 70°C. The initial drying rate of beetroot slices was 1.419 g of water removed / 100 g of bone dry matter per minute and decreases up to the 2×10^{-4} g of water removed / 100 g of bone dry matter per minute at 40°C; 1.476 g of water removed / 100 g of bone dry matter per minute and decreases up to the 4.52×10^{-4} g of water removed / 100 g of bone dry matter per minute at 50°C; 1.519 g of water removed / 100 g of bone dry matter per minute and decreases up to the 1.81×10^{-5} g of water removed / 100 g of bone dry matter per minute at 60°C and 1.764 g of water removed / 100 g of bone dry matter per minute and decreases up to the 1.11×10^{-5} g of water removed / 100 g of bone dry matter per minute at 70°C. From Fig.3 it clear that the drying took place in falling rate period. As the temperature of drying increases from 40°C to 70°C the drying rate also increases.

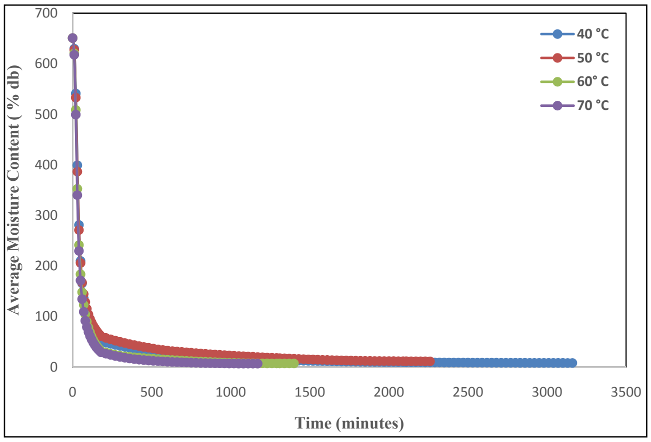


Fig. 2: Moisture content %(db) versus time (min) by convective air drying at different temperature for beetroot slices

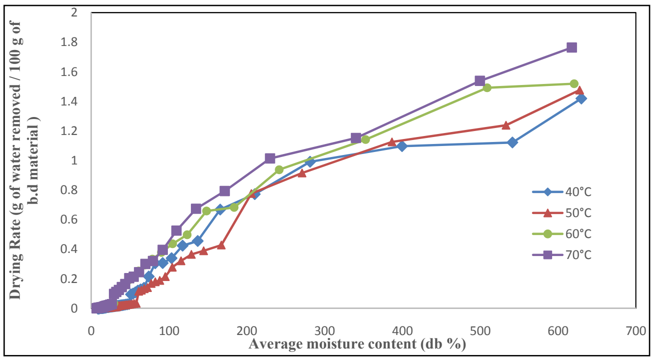


Fig. 3: Drying rate (g water removed/100 g of bone dry material/min) versus moisture content % (db) of beetroot slices dried by convective air drying method at different drying temperature

Moisture removal inside the beetroot slices at 70°C was higher and faster than the other investigated temperature. Migration of surface moisture and evaporation rate from the surface to the air decreases with decrease of the moisture in the product. The shorter time of drying was observed at higher temperature thus increased drying rate (Zhu and Shen, 2014). This increase in drying rate because of the increased heat transfer potential between the air and beetroot slices which favours the evaporation of water from beetroot slices. Similar observations reported in the literatures for Parsley leaves, Asian white radish and orange slices by the Akpinar *et al*. (2006), Lee *et al*. (2009) and Rafiee *et al*. (2010). The drying rate values are in agreement with the values obtained for Peach slices, Kokum rind and Grape leaves reported by Zhu and Shen, (2014), Hande *et al*. (2014) and Doymaz, (2012) respectively.

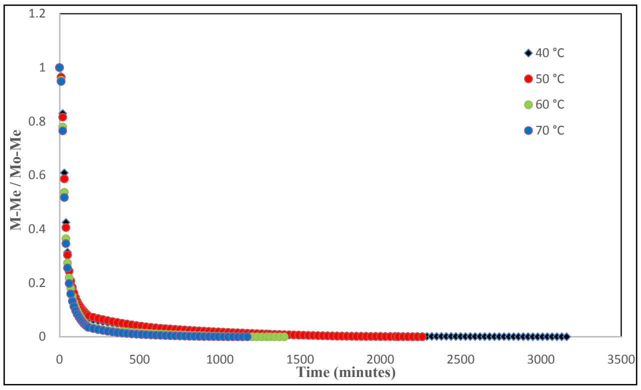


Fig. 4: Variation in moisture ratio with respect to time, min for beetroot slices during tray drying

Fig. 4 shows variation in moisture ratio with respect to time in minute. During the drying experiment moisture ratio decreases from 1 to 0.563×10^{-8}, 1 to 6.91×10^{-9}, 1 to 2.37×10^{-6} and 1 to 7.68×10^{-10} at the drying temperature of 40°C, 50°C, 60°C and 70°C respectively. The results obtained were in agreements with those reported by Hande *et al.* (2014).

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 Newton model, Page model, Henderson and Pabis, Exponential, Modified page, Thompson etc. Among the models fitted to the experimental data at 40°C, 50°C, 60°C and 70°C the modified page model was well fitted to the experimental data with $r^2 \geq 0.969$; MSE$\leq$ 0.000840 and chi square (χ^2) $\geq$ 0.10155. Linear regression analysis was done according to the six 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 different temperature. In all cases r^2 values for the models were greater than 0.9691 indicating a good fit. The model parameter i.e., '*k*' 4.193, 4.0519, 0.28402 and 0.2652 at 40°C, 50°C, 60°C, 70°C respectively. The 'L' was 1.3389, 1.395, 4.05735 and 3.9344 for the 40°C, 50°C, 60°C, 70°C respectively. Value 'n' were 1.1862, 1.0684, 1.20973 and 1.2648 for the 40°C, 50°C, 60°C, 70°C respectively. The '*k*' value increases with increase in temperature from 40°C to 70°C. 'L' value decreases for the increase in the temperature from 40°C to 70°C. Also the '*n*' value increases with the increase in the temperature. Similar trends were observed for blanched sweet potato slices (Falade and Solademi, 2010), also for pineapple drying (Olanipekun *et al*. 2015).

Effective moisture diffusivity

Fig. 5 shows Ln (MR) versus time (minute) for convective hot air drying of beetroot slices dried at 40 °C, 50 °C, 60 °C and 70 °C respectively. The graph shows 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). Table (3) shows the effective diffusivity of beetroot slices dried at 40°C, 50°C, 60°C and 70°C. The diffusivity values were in the range of 2.10962×10^{-9} to 1.34691×10^{-8} for all the temperature. As the temperature increases the diffusivity value increases $2.10962 \times 10^{-9} m^2/s$, $5.03063 \times 10^{-9} m^2/s$, $1.03858 \times 10^{-8} m^2/s$, $1.34691 \times 10^{-8} m^2/s$ from 40°C, 50°C, 60°C and 70°C respectively. The effective diffusivity used to explain the mechanism of moisture movement during drying and complexity of the process (Kashaninejad *et al*. 2007; Falade and Solademi, 2010.). Generally, effective moisture diffusivity increased with increased air temperature (Falade and Solademi, 2010).

Table 2: Model parameters, R^2, RMSE and Chi square values of beetroot slices dried by Convective hot air drying at 40°C, 50°C, 60°C and 70°C

Sl. No.	**Model name**	**Temperatures**															
		40°C				**50°C**				**60°C**				**70°C**			
		Model Parameters	**R²**	**MSE**	**Chi**	**Model Parameters**	**R²**	**MSE**	**Chi**	**Model Parameters**	**R²**	**MSE**	**Chi**	**Model Parameters**	**R²**	**MSE**	**Chi**
1	Newton	*k* = 0.018788150	0.969169107	0.000950469	0.112155330	*k* = 0.019066905	0.968723492	0.001248553	0.109872663	*k* = 0.021739674	0.981439177	0.001001978	0.059116679	*k*=0.022934081	0.980762419	0.001159525	0.059135790
2	Page	*k* = 0.008898940 *n*=1.186222688	0.972084401	0.000867950	0.101550194	*k* = 0.014499589 *n* = 1.068444177	0.969174049	0.001244711	0.108289882	*k* = 0.009587723 *n* = 1.209743049	0.985380247	0.000802832	0.046564272	*k*=0.008293552 *n*=1.264864559	0.986332052	0.000840298	0.042014894
3	Modified Page	*k* = 0.018675272 *n*=1.186218103	0.972084401	0.000867950	0.101550194	*k* = 0.019016832 *n* = 1.068440468	0.969174049	0.001244711	0.108289882	*k* = 0.021460575 *n* = 1.209737866	0.985380247	0.000802832	0.046564272	*k*=0.022623388 *n*=1.264847206	0.986332052	0.000840298	0.042014894
4	Exponential	*k* = 0.018788150	0.969169107	0.000950469	0.112155330	*k* = 0.019066905	0.968723492	0.001248553	0.109872663	*k* = 0.021739674	0.981439177	0.001001978	0.059116679	*k*=0.022934081	0.980762419	0.001159525	0.059135790
5	Thompson	*a* = 1.41295E+02 *b* = 6.31244E+01	0.994889498	1.56275E+04	1.82842E+06	*a* =-1.26736E+02 *b* =-3.195781491	0.940144867	9.14923E+04	7.95983E+06	*a* = -5.64949E+01 *b*=-0.181087032	0.956882189	2.39142E+04	1.38702E+06	*a* = -5.54874E+01 *b* = -1.316634389	0.946679482	1.98512E+04	9.92561E+05
6	Modified Page equation-II	*k*=4.193163414 *L*=1.33898E+01 *n*=1.186216922	0.972084401	0.000867950	0.101550194	*k*=4.051984658 *L*=1.39572E+01 *n*=1.068454851	0.969174049	0.001244711	0.108289882	*k*=0.284023442 *L*=4.057352862 *n*=1.209730778	0.985380247	0.000802832	0.046564272	*k*=0.265237783 *L*=3.934438580 *n*=1.264856655	0.986332052	0.000840298	0.042014894

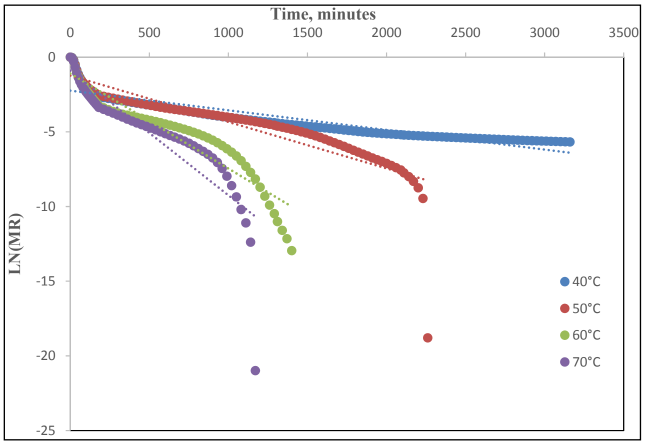


Fig. 5: Ln(MR) versus time, minutes for effective diffusivity for convective hot air drying of beetroot slices

It was observed that D_{eff} values increased greatly with increasing drying temperature and thickness. When samples are dried at higher temperature, increased heating energy would increase the activity of the water molecules leading to higher moisture diffusivity (Xiao *et al*. 2010).

Table 3: Values of effective diffusivity and activation energy of beetroot slices at different temperatures

Temperature, °C	D_{eff} (m²/s)	E_a (kJ/mole)
40°C	2.10962×10^{-9}	0.8160
50°C	5.03063×10^{-9}	
60°C	1.03858×10^{-8}	
70°C	1.34691×10^{-8}	

The values obtained of effective diffusivity from this study was 2.10962×10^{-9}m²/s, 5.03063×10^{-9}m²/s, 1.03858×10^{-8}m²/s, 1.34691×10^{-8}m²/s during the drying temperature of 40°C, 50°C, 60°C, 70°C respectively. Similar results have been observed for sweet potato slices ranged from 1.25×10^{-10} m²/s to 1.68×10^{-9} m²/s and 2.28×10^{-10} m²/s to 9.75×10^{-9} m²/s for first and second falling rates respectively (Falade and Solademi, 2010.), also this values lie within the general range of 10^{-11} to 10^{-6}m²/s reported by Zogas *et al*. (1996) and Marinos-Kourisand Maroulis (1995) for the food material. Srikatden and Robert (2003) also the reported the moisture diffusivity range of potato, carrot core, carrot cortex and apple as 4.88×10^{-10}-1.02×10^{-9}m²/s. Over the range of 50-80°C, moisture diffusivities varied from 9.92×10^{-8}-1.02×10^{-7} and 0.829×10^{-6}-1.298×10^{-5}m²/s for *D. alata* and *D. rotundata* respectively (Falade *et al*. 2007).

Activation energy for drying of beetroot slices

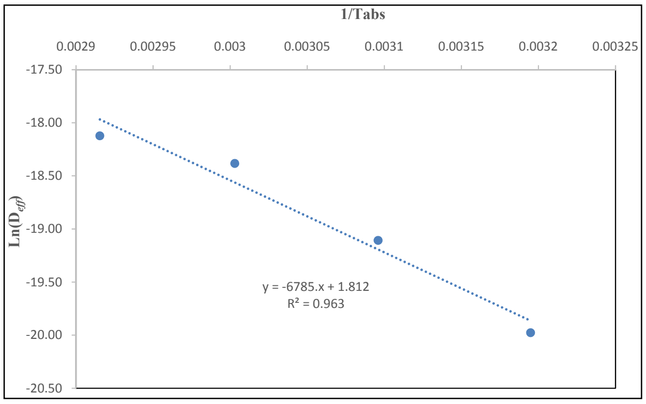


Fig. 5: Ln(D_{eff}) vs 1/Tabs for dried beetroot slices

Fig. 6 shows the Ln(D_{eff}) vs 1/T_{abs} for dried beetroot slices at 40°C, 50°C, 60°C and 70°C. The activation energy was calculated by plotting the natural logarithm of D_{eff} vs reciprocal of absolute temperature showed straight line in the range of air temperature studied. The activation energy E_a for moisture diffusion calculated from the slope of straight lines graphs are given in Table (3). The activation energy for moisture diffusion was found to be 0.8160 kJ/mole. The energy of activation (E_a) are reported in the literature, for convective hot air drying of yam slices was 8.831 kJ/mole (Sobukola *et al*. 2008), also E_a for sweet potatoes slices was 15 kJ/mole (Fan *et al*. 2015), for apple slices 19.96-22.62 kJ/mole (Kaya *et al*. 2007), for sweet potato cubes 11.38 kJ/mole (Singh and Pandey, 2012), for sweet potato slices 22.7-23.2 kJ/mole (Doymaz, 2011). Generally, beetroot slices show the lower activation energy due to its higher moisture diffusivity as discussed above. So a beetroot slice requires the lower activation energy for the mass diffusion during hot air drying.

The results indicated a linear relationship between (Ln D_{eff}) and (1/T_{abs}) as plotted in Figure 5 for beetroot slices dried by convective drying at 40°C, 50°C, 60°C and 70°C. The diffusivity constant or pre- exponential factor of Arrhenius equation (D_0) and activation of energy (E_a) calculated from the linear regression are 6.122 m^2/s and 0.8160 kJ/mol for beetroot slices Equation(10) shows the effect of temperature on effective diffusivity of beetroot slices.

$$D_{eff} = (6.122)\,\exp.\left(\frac{0.8160}{R(T+273.15)}\right)$$

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 drying. Moisture content of fresh beetroot slices was 669.89±2.1 (% db) and it decreases from 10.76±0.03 (% db) to 11.46±0.01 (% db), 7.21±0.01 (% db) and 6.94±0.36 (% db) at 40**°C**, 50**°C**, 60**°C** and 70**°C** temperature after drying respectively. It is observed from the data presented in Table 4 & 5 that the moisture content of beetroot was decreases significantly. The decreases of moisture content were significant at $p \leq 0.01$.

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 to 62±4.00 (°B) to 63.33 ±2.860 (°B) at 40°C, 50°C, 60°C and 70°C temperature after drying respectively. It is observed from the data presented in Table 4 and 5 that the total soluble solid of beet root was 62, 62.40, 62.90 and 63.33°B at 40°C, 50°C, 60°C and 70°C respectively. The increases in total soluble solid of beetroot slices after hot air drying might be attributed due to moisture inside the cell membrane started diffusing outward from centre to surface and sub-surface water to ambient and leaving behind solid content. With progression of drying, most of free water evaporated and only solid remained. The increase of total soluble solid was significant at $p \leq 0.01$. The values are in agreement with values obtained for guava juice powder reported by Mahendra *et al.* (2010) total soluble solid are in the range of 35.4°B to 36°B, also for the cashew apple fruit powder total soluble solid is 40.38°B (Costa *et al.* 2009).

3. pH

Table 4 (c) shows the pH of beetroot fruit and slice powder before and after drying at 40°C, 50°C, 60°C and 70°C temperature respectively. The pH of beetroot slices was 7.27±0.15 before drying and then after drying of beetroot slices with final pH as 6.3±0.15, 6.40±0.38, 6.5 ±0.06 and 7.10±0.10 at the temperature 40°C, 50°C, 60°C and 70°C respectively. The increase of pH content was significant at $p \leq 0.01$. Similar kind of result has been observed during drying of cashew apple fruit powder (Costa *et al.* 2009) ; Osorio *et al.* (2009) reported for guava powder, Mahendra *et al.* (2010)) reported for freeze –dry guava juice powder .

4. Titratable acidity

Table 4 (d) shows the titratable acidity of beetroot slices and slice powder before and after drying at 40°C, 50°C, 60°C and 70°C temperature respectively. Titratable acidity of beetroot slices decreases from 1.03±0.19 to 0.58 ±0.16%. The titratable acidity was 0.31±0.21 % of fresh beetroot slices. It is observed from Table 3 and 4 that the titratable acidity of beet root was 1.03, 0.80, 0.66 and 0.58 % at 40°C, 50°C, 60°C and 70°C respectively. The decreases in titratable acidity of beetroot slices with respect to increase in drying temperature of 40°C, 50°C, 60°C and 70°C respectively might be attributed due to rapid removal of water present in the slices as a result of increase in temperature .The decrease of titratable acidity content was significant at $p \leq 0.01$. Similar kind of result has been observed during drying of cashew apple fruit powder (Costa *et al.* 2009); sweet-bell paper by convective drying (Sharma *et al*. 2014).

5. Reducing Sugar

Table 4 (e) shows the reducing sugar of beetroot fruit and slice powder before and after drying different temperature. The reducing sugar of fresh beetroot was 0.29 ± 0.03 and it increases from 4.25±0.008 to 4.66±0.09%. 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≤0.01. Similar behaviour has been observed by Maskan *et al*. (2002) during drying of grape leather (Pestil), Sharma, Joshi and Kaushal, (2014) reported the reducing sugar content of fresh sweet-bell paper was 2.08±0.13 % and 5.08±0.85 % after drying, Cholera (2010) for osmo-air guava dried powders; Costa *et al*. (2009) for cashew apple fruit.

6. Total Sugar

Table 4 (f) shows the total sugar of beetroot slices and slice powder before and after drying different temperature. 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 increase from 33.53, 39.82, 41.50 and 41.78 per cent at 40, 50, 60 and 70˚C respectively. The increase of total sugar content was significant at p≤0.01. Similar behaviour has been observed by Hymavathi and Khader (2005), total sugar in mango powder and Uchoa *et al.* (2009), found the total sugar content of the cashew apple fruit powder dried in the tray dryer was 30.60 %.

7. Hardness

Table 4(g), shows the hardness of beetroot slices at 40°C, 50°C, 60°C and 70°C temperature. Hardness of beetroot slices were observed in the range of 29.027 to 72.373(N). Hardness increases with increase in the temperature. The increase in hardness with increase in temperature was observed due to shrinkage of dehydrated sample that led to quick transport rate of water molecules. The compact and shrunk structure as obtained at highest air temperature i.e. 70°C is 72.373 N. The increase of hardness of beetroot slices was non-significant at p≤0.01. The results obtained were in agreements with those reported by Kaur and Singh., (2014) for dehydrated beetroot slices; sweet potato, apple and garlic slices (Xiao *et al*. 2009; Abano *et al*. 2011 respectively). The maximum value for hardness was observed at drying temperature of 70°C.

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 at 40°C and it decreases up to 26.108**±**0.12 at 70°C drying. The decrease of colour pigment was significant at p≤0.01. Similarly before drying a was 31.50±0.85 and after drying it decreases up to 28.78±0.12, There was specific trend were observed for b value. b value of beetroot slices was 9.10±0.16 and after drying it was from 9.35±0.07 to 13.636± 0.06. This variation in

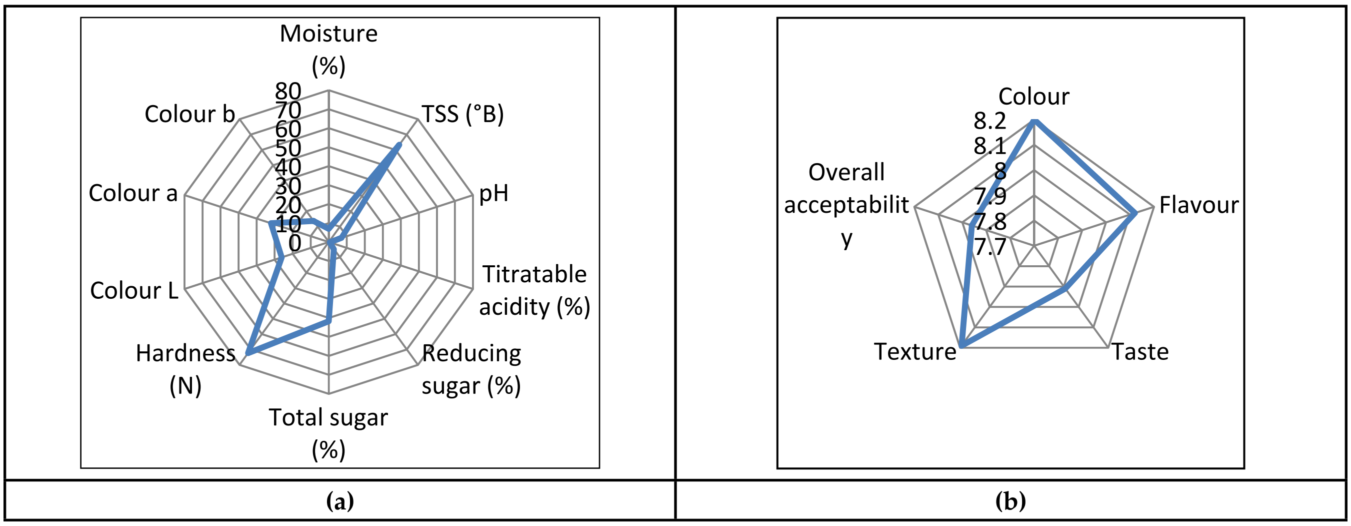
Table 4: Chemical composition of beetroot slices before and after drying

Sl. No.	Chemical constituents	Before Drying	After drying			
			40°C	50° C	60°C	70°C
(a)	Moisture %db	669.89±2.13	10.76±0.03	11.46±0.01	7.21±0.01	6.94±0.36
(b)	T.S.S °B	10 ± 2.00	62±4.00	62.40±2.31	62.80±2.31	63.33±2.31
(c)	pH	7.27 ± 0.15	6.3±0.15	6.40±0.38	6.50±0.06	7.10±0.10
(d)	Titratable acidity %	0.31 ± 0.21	1.03±0.0*	0.80±0.02*	0.66±0.02	0.58±0.05
(e)	Reducing sugar %	0.29 ± 0.03	4.25±0.08	4.33±0.31	4.50±0.10	4.66±0.09
(f)	Total Sugar %	18.80 ± 0.56	33.53±0.22	39.82±0.76	41.50±1.16	41.78±1.10
(g)	Hardness N		29.027*	36.873*	65.802*	72.373*
(h)	Colour L	33.69±0.12	27.28±0.08	28.66±0.01	26.016±0.01	26.10±0.01
	a	31.50 ± 0.85	41.078±0.03	31.832±0.39	28.78±0.01	32.08±0.03
	b	9.10 ± 0.16	10.19±0.03	10.13±0.02	9.35±0.07	13.63±0.06

**values are non-significant at p≤0.01.*

Table 5: ANOVA table

Sl. No.	Parameter	Moisture	T.S.S	Acidity	Total sugar	Reducing sugar	pH	Hardness	Colour		
									L*	a*	b*
1	$S.E_m$ (5%)	1.03	1.63	0.02	0.51	0.10	0.305371	1.84	0.02	0.11	0.03
2	C.D (5%)	3.38	5.33	0.06	1.68	0.33	0.40	6.01	0.07	0.34	0.09
3	S.D	0.74	2.860	0.749	3.682	0.285	1.057835	0	0.02	0.12	0.06
4	D.f (Bet-group)	3	3	3	3	3	3	3	3	3	3



(a) (b)

Fig. 9: (a) mechanical properties and **(b)** sensory properties of best treatment of convective hot air drying of beetroot slices

colour is due to pigment degradation because of long drying duration.

Co-relation between the objective and subjective scores

For the best treatment, the beetroot slices dried at 70°C temperature in convective hot air drying achieved the desirable qualities i.e. moisture content 6.94 (%), total soluble solid 63.33 (°B), pH 7.1, titratable acidity 0.58 (%), reducing sugar 4.66 (%), total sugar 41.78 (%) and colour value 26.1,32.02 and 13.63 (L, a and b respectively).

The best sensory score of the product have been obtained from sensory analysis which was dried at 70°C in convective hot air drying had achieved the highest colour 8.20, flavour 8.12, texture 8.9 and taste 7.91 with overall acceptability 7.96.

From the both mechanical properties, colour measurement and from sensory score the best product i.e. beetroot slices dried at 70°C in convective hot air drying it was concluded that it satisfactorily retains the quality parameter with desirable quality.

CONCLUSION

1. Convective hot air drying of beetroot slices reduces the moisture from the 650.750–10.76 % (db), 650.750–11.46% (db), 650.750–7.21% (db) and 650.750–6.94 % (db) had taken the 53 h, 38h, 24h, 19h for drying at 40˚C, 50˚C, 60˚C and 70˚C respectively.
2. The drying rate for beetroot slices was 1.76 g of water removed/ 100 g of bone dry matter per minute was highest at 70°C followed by 1.51 g of water removed/ 100 g of bone dry matter per

minute at 60ºC and also 1.47 g of water removed /100 g of bone dry matter per minute at 50ºC while that for the 40ºC beetroot slices which was 1.41 g of water removed/ 100 g of bone dry matter per minute.

3. Hot air cabinet drying of beetroot slices indicated that Modified page model was fitted well to the experimental data. The characteristics constants of Modified Page model are k = 4.193163414 with R^2 = 0.972084, chi square (χ^2) ≥ 0.10155 and $RMSE$=0.000867.
4. Also the Effective Moisture Diffusivity was found to be from this study was 2.10962 × 10^{-9} m^2/s, 5.03063 × 10^{-9} m^2/s, 1.03858 × 10^{-8} m^2/s, and 1.34691 × 10^{-8} m^2/s at drying temperature of 40˚C, 50˚C, 60˚C, 70˚C respectively.
5. Activation Energy needed for the moisture movement from the beetroot slices at 40˚C, 50˚C, 60˚C, 70˚C during drying was found to be 0.8160 kJ/mole.
6. From the above results it can be concluded that convective 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.
7. There are significantly increase in the total soluble solid from 62±2.860 to 63.33±2.860°B, there are decrease in the titratable acidity of beet root 1.03±0.749to 0.58±0.749%, The reducing sugar increases from 4.25±0.005 to 4.66±1.22% at, also increase in total sugar from 33.53±3.682 to 41.78±3.682 %, hardness increases from 29.027±0 to 72.373±0 N, also there are decrease in colour values L*, a*, b*, after drying at 40˚C, 50˚C, 60˚C and 70˚C respectively 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, m^2/s
R^2	Radius, m

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