International Journal of Food and Fermentation Technology
Citation: *Int. J. Food Ferment. Technol.*, **16**(01): 129-145, June 2026
DOI: 10.30954/2277-9396.01.2026.9

ASSOCIATION FOR AGRICULTURE ENVIRONMENT AND BIOTECHNOLOGY

RESEARCH PAPER

Microwave-Convection Drying of Beetroot Slices and Its Quality Evaluation

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Paper No.: 352 **Received:** 12-04-2026 **Revised:** 14-05-2026 **Accepted:** 27-05-2026

ABSTRACT

Drying characteristics of beetroot slices was investigated by microwave-convection drying method at the temperature 40°C, 50°C and 60°C of 4 mm thickness beetroot slices. Beetroot has the many medicinal, pharmaceutical and functional properties. Ten drying model i.e. Newton model, Page model, Henderson and Pabis, Exponential, Modified page, Thompson, Wang and Singh, Midilli, Simplified Ficks Diffusion (SFFD) equation and Modified page equation-II etc. were fitted to the experimental data on moisture ratio with respect to time. Modified Page drying model best fitted with $r^2 \geq 0.9910$; MSE ≤ 0.0009 and chi square (χ^2) ≥ 0.0655 to experimental moisture ratio with respect to time. Effective diffusivity for beetroot slices dried at different temperature was 1.6552×10^{-7}, 2.3465×10^{-7} and 3.2131×10^{-7} for 40°C, 50°C and 60°C temperature respectively. The activation energy (E_a) for moisture diffusion was found to be 3.67 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 and 60°C respectively were also determined and discussed.

Keywords: Microwave-convection drying, moisture ratio, drying behaviour, drying models, effective diffusivity (D_{eff}), activation energy (E_a) 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 *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 μ mol/dry weight (Kajkonen *et al.* 1999; Vinson, Hao, Su, Zubik, 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, 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

How to cite this article: Nale, S.A. and Swami, S.B. (2026). Microwave-Convection Drying of Beetroot Slices and Its Quality Evaluation. *Int. J. Food Ferment. Technol.*, **16**(01): 129-145.

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

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 blood stone (Sharama., 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. Betalines are antioxidants and having profound health benefits.

Fresh beetroot contains high moisture content (75% 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*. 2004); Shynkaryk *et al*. 2008). Convection drying as well as other techniques for drying is used in order to preserve the original characteristics of foods.

New drying processes, including combined methods, have been developed to increase the dehydration rate and simultaneously improve the quality of dehydrated products. Microwave-assisted air drying is a promising technique for plant foods, due to the shorter drying time and better quality of the resulting products Huxsoll *et al*.(1968); Garcia *et al*. (1988); Torringa *et al*. (1993); Bouraoui *et al*. (1994); Venkatachalapathy *et al*. (1998); Ramaswamy *et al*. (2000). These advantages are mostly due to the fast, instantaneous, volumetric heating caused by microwave energy.

Microwave energy combined with other drying methods can improve the drying efficiency as well as the quality of food products which is far better than that achievable by the application of each method alone (Botha *et al*. 2012). In the case of microwave–convective drying, both energy sources influence the drying. The energy from the microwave waves is absorbed by water molecules in the interior of the products. Such molecules, moved to the food surface, removed by convective heated air current (Jiao *et al*. 2014). The use of intermittent microwave–convective led to a dried product with improved physical, nutritional and chemical characteristics (Bantle, Käfer and Eikevik, 2013; Esturk and Soysal, 2010). Fast microwave drying also results in non uniformity of heating, leading in some cases to overheating and charring of dried product. Schiffmann, (1995) pointed out the different ways to combine microwave energy and hot air during drying. Although hot air has a relevant role to improve non uniformity, the intensity of microwave energy absorbed by the product during drying has a prevailing effect on overheating. The most common way of applying the microwave energy in microwave drying is constant power. Thereby the magnetron supplies the load with a constant amount of microwave energy.

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 microwave convection dryer for Potato, jackfruit, okra, Carrot pieces, Fig, Guava, Jujubes, figs, Pine-apple, Beetroot slices, red pepper, bay leaves, red bell paper, single apricots apple, anola shreds, potato, cape gooseberry, peach slices, sweet potato slices (Wang *et al.*2004, Srinang *et al.* 2014; Mana *et al.* 2012; Yan *et al*. 2010; Abdul-Fadl *et al.* 2015; Sharma and Yadav, 2017; Gao *et al*. 2012; Correa *et al*. 2011; Kaur and Singh, 2014; Figiel, 2010). No reports are available so far for drying of beetroot slices by microwave-convection 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. 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 ^{o}C ±1 ^{o}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).

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

Where,

W_1 = Weight of sample before drying, g

W_2 = Weight of sample after drying, g

Experimental setup for microwave-convection drying

Microwave-convection 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 microwave convective batch dryer (Make M/s. Twin Engineering, Vadodara, Gujarat; Model: TW/CMDRY/2/17-18) having capacity of 3 kW with maximum output of 625W at 2450MHz and drying chamber having dimensions 900 mm × 900 mm × 600 mm (*L* × *W* × *H*). The dryer had the capability of convective temperature adjustment at fixed power (wattage) adjustment.

After setting the desired temperature (40, 50 and 60°C) in the temperature controller the microwave convective dryer was run empty for around 30 min to achieve the desired set point temperature. The initial moisture content of the beetroot slices was determined and sample were on the sample holder, which was then placed at the centre of the turntable in the microwave cavity having diameter of 350 mm. There are two sample holder arranged in stacking one above the other placed on turning plates of the same rotor. After achieving the set point temperature the beetroot slices were loaded on the sample holder in a single layer by placing the slices on rotating plate of microwave convective dryer. The temperature of the convective air was varied up to 40^{o}C, 50^{o}C and 60^{o}C temperature and the microwave power was kept constant at 50W. The ON and OFF time of the magnetron was adjusted at 20 sec ON and 40 sec OFF respectively. Moisture loss in the sample was measured by recording the weight of the sample after 2 minutes interval by using digital weighing balance (Make M/s Contact Mode: CA) till the constant weight was achieved. It was observed for three constant weight reading. When the material acquired a constant weight, the equilibrium moisture content was assumed to be reached (Maskan, 2000). The dried beetroot slices were then transferred into low density polyethylene and aluminium laminated pouches and cooled to the room temperature in desiccators for quality analysis. The moisture content with respect to the time was calculated from drying data. The drying data includes initial moisture content, weight loss w.r.t. time, average moisture content with respect the time, drying rates (g of water removed per 100g of bone dry matter per minute), moisture ratios (MR) and final moisture content of the beetroot slices were also recorded. Three replications were taken for each experiment. A schematic of the microwave convective dryer is presented in Fig. 1. Fig. 1 shows the microwave convective dryer system used for the experimentation.

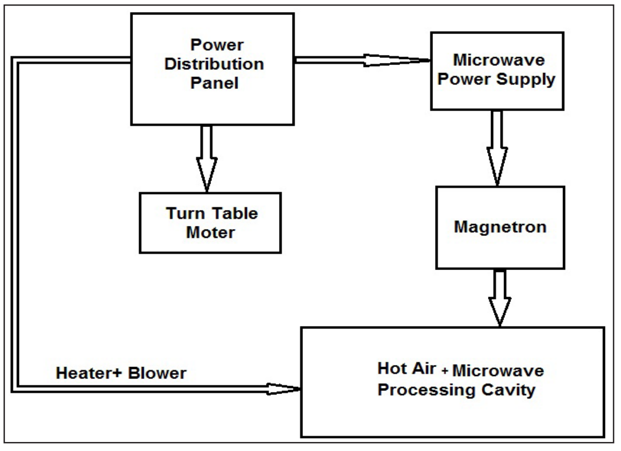

Fig. 1: Schematic of microwave convective dryer

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 microwave convection 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 microwave convection 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) Drying rate

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

$$R = \frac{Wr}{T \times Wd} \times 100 \quad \ldots(2)$$

Where,

R = Drying rate (g/min)

Wr = Amount of moisture removed (g)

T = Time taken (min)

Wd = Total bone dry weight of sample (g)

(b) Moisture ratio

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

$$\text{Moisture ratio} = \frac{M - M_e}{M_0 - M_e} \quad \ldots(3)$$

Where,

M_R = Moisture ratio

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

M_e = EMC, % (db)

M_0 = Initial moisture content, %(db)

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) and RMSE values, the better is the goodness of fit (Ozdemir *et al.* 1999; Ertekin and 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 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:

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

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:

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

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:

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

Where,

L = half thickness

1. 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 is obtained by plotting the natural logarithm of D_{eff} against the reciprocal of absolute temperature. Lopez *et al*. (2000) and Simal *et al.* (1996) related temperature with Arrhenius expression as:

$$D_{eff} = D_0.\exp.\left(\frac{-E_a}{R\left(T + 273.15\right)}\right) \quad \ldots(10)$$

Where,

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

E_a = is the activation energy (kJ/mol)

T = is the temperature of air, (°C)

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

Rearranging Equation (10) gives Equation (11):

$$InD_{eff} = InD_0 - \frac{E_a}{R\left(T + 273.15\right)} \quad \ldots(11)$$

Energy of activation can thus be calculated from Equation (11), which gives a relationship between temperature and effective moisture diffusivity. The plot of InD_{eff} 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	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	$MR = \alpha\ exp(-kt^n) + bt$	Sacilik *et al.* 2006
7	Wang and Singh	$MR = 1 - a.t + b.t^2$	Zhu and Shen., 2014; Wang and Singh, 1978
8	Midilli *et al.*	$MR = a.exp(-k.t^n) + b.t$	Midilli *et al.* 2002
9	SFFD model	$MR = a\ exp(-kt^n) + bt$	Yaldiz and Ertekin, 2001
10	Modified page equation-II	$MR = a\ exp(-kt^n)$	Zhang and Litchfield, 1991

Evaluation of Quality parameters for the beetroot powder Product

1. Total soluble solids

Total soluble solids was determined for fresh slices and dried after 40°C, 50°C and 60°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 slices and dried slices after 40°C, 50°C and 60°C was measured using digital pH meter (Make M/s: Hanna instrument, Model: HI98127). 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 and 60°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 and 60°C 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 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

4. Reducing sugars

The reducing sugars was for beetroot juice and slice powder after drying at 40°C, 50°C and 60°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 % =

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

Where,

GV = Glucose value

5. Total sugars

Total sugars was estimated was for beetroot juice and slice powder after drying at 40°C, 50°C and 60°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 (%) =

$$\frac{\text{Factor} \times \text{Dilution}}{\text{Titre reading} \times \text{Weightn of sample}} \times 100 \quad \ldots(14)$$

6. 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).

7. 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).

RESULTS AND DISCUSSION

Drying Kinetics

Fig. 2 shows moisture content (db) % with respect to time (min) of beetroot slices dried by microwave convection drying. The beetroot slices were dried from an average initial moisture content of 520.347% (db) to 8.87±0.21% (db) at 40°C, from 520.347% (db) to 6.75±0.78% (db) at 50°C and from 520.347% (db) to 6.51±1.002% (db) at 60°C. It took around 74 minutes, 60 minutes and 44 minutes for drying of beetroot slices by microwave convection drying at 40°C, 50°C and 60°C to complete the drying process.

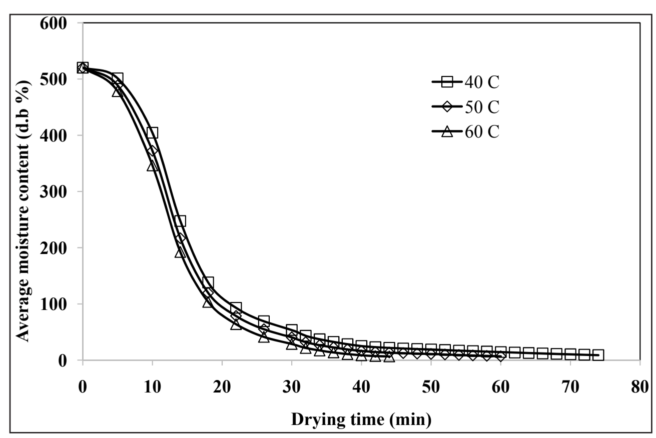

Fig. 2: Moisture content %(db) versus time (min) by microwave-convection drying at different temperature for beetroot slices

Fig. 3 shows the drying rate (g water removed/100 g of water removed /min) with respect to moisture content % (db) of beetroot slices dried by microwave convection drying at 40°C, 50°C and 60°C. From Fig.

3 it represents the, curve of drying rate of beetroot slices versus drying time , the drying rate of beetroot slices were decreased from 5.55 g of water removed / 100 g of bone dry matter per minute to the 0.011 g of water removed / 100 g of bone dry matter per minute, from 6.020 g of water removed /100 g of bone dry matter per minute to the 0.08 g of water removed / 100 g of bone dry matter per minute and 7.98 g of water removed / 100 g of bone dry matter per minute to the 0.023 g of water removed / 100 g of bone dry matter per minute for the drying temperatures of 40°C, 50°C and 60°C respectively.

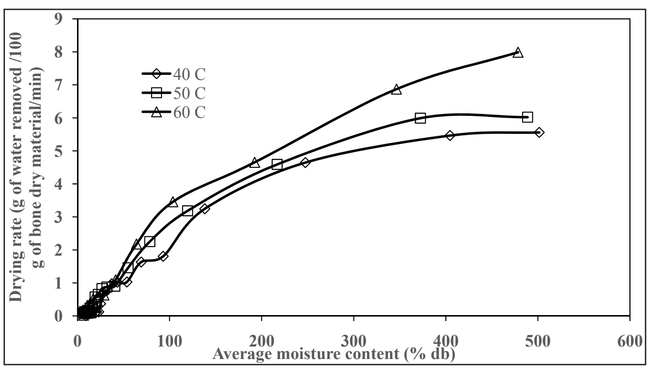

Fig. 3: Drying rate (g water removed/100 g of bone dry material/min) versus moisture content % (db) of beetroot slices dried by microwave convection drying method at different drying temperature

Drying took place in the falling rate period for the all the temperature. As the temperature of drying increases from 40°C to 60°C, drying rate increases for the all the temperature. Moisture removal inside the beetroot slices at 60°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 is 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. in the range of 5 to 6 g of water removed / 100 g of bone dry matter per minute at 60°C, 1.58 g of water removed / 100 g of bone dry matter per minute at 60°C and 0.01 to 0.05 kg of water removed / kg of bone dry matter per minute at 40°C, 50°C and 60°C reported by Zhu and Shen, (2014), Hande *et al*. (2014) and Doymaz, (2012) respectively.

Fig. 4 shows variation in moisture ratio with respect to time in minute. During the drying experiment moisture ratio decreases from 1 to 1.31×10^{-6}, 1 to 1.81×10^{-7} and 1 to 1.82×10^{-6} at the drying temperature of 40°C, 50°C and 60°C respectively.

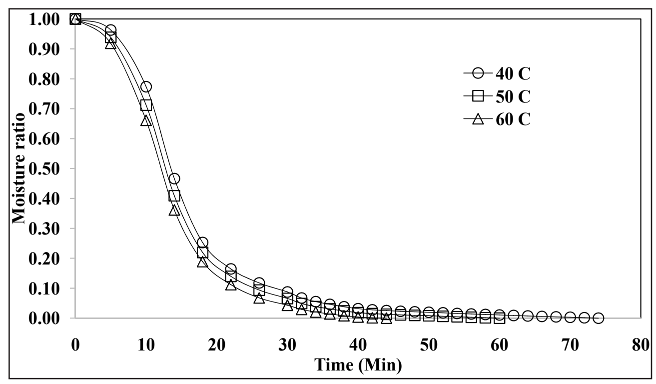

Fig. 4: Variation in moisture ratio with respect to time, min for beetroot slices during tray drying

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, Wang and Singh, Midilli, Simplified Ficks Diffusion (SFFD) equation and Modified page equation -II etc. Among the ten models fitted to the experimental data at 40˚C, 50˚C and 60˚C the modified page model was well fitted to the experimental data with $r^2 \geq 0.9910$; $MSE \leq 0.0009$ and chi square (χ^2) ≥0.065. Linear regression analysis was done according to the ten 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

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 and 60°C

Sl. No.	Model name	Temperatures											
		40°C				50°C				60°C			
		Model Parameters	R²	MSE	Chi	Model Parameters	R²	MSE	Chi	Model Parameters	R²	MSE	Chi
1	Newton	k=0.065245890	0.944440169	0.005502771	0.159580347	k=0.070824738	0.947744618	0.006277082	0.138095807	k=0.075982051	0.948346542	0.009105298	0.127474167
2	Page	k=0.003318632 n=2.020151413	0.991011555	0.000922030	0.025816840	k=0.003749467 n=2.032030699	0.994717842	0.000664724	0.013959210	k=0.003692203 n=2.091391706	0.997354482	0.000502216	0.006528802
3	Modified Page	k=0.059271143 n=2.020135689	0.991011555	0.000922030	0.025816840	k=0.063988924 n=2.032017279	0.994717842	0.000664724	0.013959210	k=0.068674605 n=2.091386197	0.997354482	0.000502216	0.006528802
4	Henderson and Pabis	a=1.159917110 k=0.072251962	0.957829991	0.004325777	0.121121764	a=1.146133981 k=0.077754433	0.959419162	0.005106827	0.107243375	a=1.135245215 k=0.083044036	0.958627873	0.007853935	0.102101149
5	Exponential	k=0.065245890	0.944440169	0.005502771	0.159580347	k=0.070824738	0.947744618	0.006277082	0.138095807	k=0.075982051	0.948346542	0.009105298	0.127474167
6	Wang and Sing	a=-0.039147149 b=0.000365170	0.943577137	0.005787827	0.162059170	a=-0.045311776 b=0.000496901	0.966386529	0.004230031	0.088830647	a=-0.052842198 b=0.000692570	0.977349860	0.004299820	0.055897666
7	Thompson	a=-1.56678E+01 b=-0.740399346	0.993546897	1.56822E+01	4.39101E+02	a=-5.536055996 b=-0.248059855	0.997474449	4.277201175	8.98212E+01	a=-4.671574220 b=-0.246954214	0.992378492	7.577537730	9.85080E+01
8	Midilli *et al.*	a=0.0000000001 k=8.30795E+01 n=0.000170080 b=1.0.00000000	1.000000000	0.0000000001	0.0000000001	a=1.000000000 k=-6.970935421 n=5.34661E+01 b=0.001069722	0.393799294	0.076286310	1.602012502	a=1.000000000 k=-9.668827688 n=5.36142E+01 b=0.002154081	0.429508700	0.108299999	1.407899990
9	Simplified Fick's Diffusion (SFFD) equation	a=1.159912855 c=0.117849849 L= 1.277149316	0.957829991	0.004325777	0.121121764	a=1.146129921 c=0.066233522 L=0.922950387	0.959419162	0.005106827	0.107243375	a=1.135245018 c=0.109604422 L=1.148840976	0.958627873	0.007853935	0.102101149
10	Modified Page equation-II	k=0.281472863 L=3.001299959 n=2.020135391	0.991011555	0.000922030	0.025816840	k=0.366678857 L=3.088410480 n=2.032005524	0.994717842	0.000664724	0.013959210	k=0.636491701 L=3.425259316 n=2.091372193	0.997354482	0.000502216	0.006528802

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 0.944 indicating a good fit. The model parameter i.e., '*k*' were 0.059, 0.063 and 0.068 at 40°C, 50°C and 60°C respectively. Value '*n*' were 2.020, 2.032 and 2.091 for the 40°C, 50°C and 60°C respectively. The '*k*' value increases with increase in temperature from 40°C, 50°C and 60°C respectively, also the '*n*' value increases with the increase in the temperature from 40°C, 50°C and 60°C respectively. 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 microwave-convection drying of beetroot slices dried at 40°C, 50°C and 60°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 and 60°C temperature by microwave convective dring.

The diffusivity values were 1.6552×10^{-7}, 2.3465×10^{-7} and 3.2131×10^{-7} for 40°C, 50°C and 60°C temperature respectively. As the temperature increases the diffusivity value increases 1.6552×10^{-7}, 2.3465×10^{-7} and 3.2131×10^{-7} for the 40°C, 50°C and 60°C temperature respectively. The effective diffusivity is 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 in air temperature (Falade and Solademi, 2010).

It was observed that D_{eff} values increased greatly with increasing drying temperature. 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). The non-linearity of the curves indicated that the diffusivity varied with temperature of the beetroot slices sample.

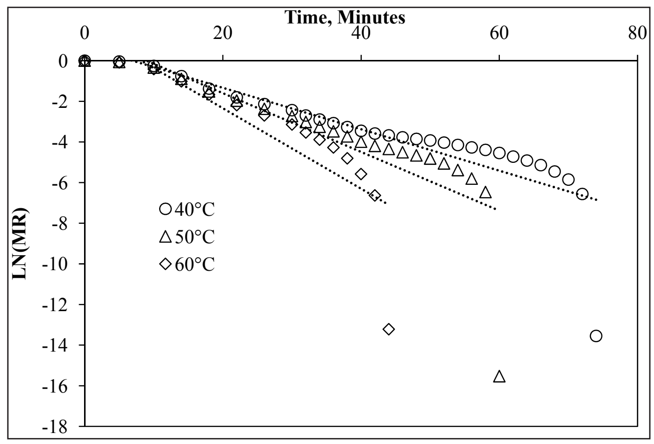

Fig. 5: *Ln*(*MR*) versus time, minutes for effective moisture diffusivity for beetroot slices dried by Microwave Convective drying

Similar kind of 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-Kouris and Maroulis (1995) for the food material. Srikatden and Robert (2003) also 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).

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	1.6552×10^{-7}	
50°C	2.3465×10^{-7}	3.67248
60°C	3.2131×10^{-7}	

Activation energy for drying of beetroot slices

Fig. 6 shows the $Ln(D_{eff})$ vs $1/T_{abs}$ for dried beetroot slices at 40°C, 50°C and 60°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 temperature studied. The activation energy E_a for diffusion calculated from the slope of straight lines graphs are given in Table (3).

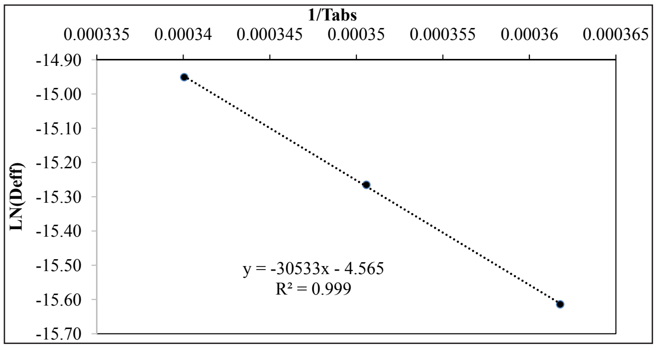

Fig. 6: *LN*(D_{eff}) vs 1/Tabs of Beetroot slices dried at varied temperatures by Microwave convective drying method

The activation energy for moisture diffusion was found to be 3.672 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).

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 520.347±8.36 (% db) and it decreases from 8.874 ±0.03%, 6.755± 0.01 and 6.515± 0.01 (% db) at 40°C, 50°C and 60°C temperature 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 $p \leq 0.01$.

2. Total soluble solid

Table 4 (b) shows the total soluble solid of beetroot fruit and slice powder before and after drying. Total soluble solid of fresh beetroot slices was 10±2.00 and it increases from 49.17±0.21°B to 51.27 ±0.24°B at 40°C, 50°C and 60°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 49.17, 50.22 and 51.27°B at 40°C, 50°C and 60°C respectively. The increases in total soluble solid of beetroot slices after microwave convection drying might be attributed due to moisture inside the cell membrane started diffusing outward from surface to ambient and leaving behind solid content. With progression of drying time, 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 different temperature. The pH of fresh beetroot slices was 7.27±0.24 before drying and then after drying of beetroot slices with final pH as 6.30 ±0.02. It is observed from the data presented in Table 4 and 5 that the pH of beet root after drying was 6.12, 6.28 and 6.30 at 40°C, 50°C and 60°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 that guava powder, Mahendra *et al*. (2010) reported that freeze dried guava juice powder.

4. Titratable acidity

Table 4 (d) shows the titratable acidity of beetroot fruit and slice powder before and after drying at different temperature i.e. at 40°C, 50°C and 60°C respectively in microwave convective drying. Titratable acidity of fresh beetroot slices was 0.31±0.21. It is observed from the data presented in Table 3 and 4 that the titratable acidity of beet root was 0.86, 0.62 and 0.55% at 40°C, 50°C and 60°C respectively. The decreases 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 combine effect of the temperature and waves radiation. 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), also similar result observed during drying of kokum rind by convective drying (Hande *et al*. 2014).

5. Reducing Sugar

Table 4 (e) shows the reducing sugar of beetroot fruit and slice powder before and after drying at different temperature. The reducing sugar of fresh beetroot slices was 0.29±0.03 %. It was observed that after microwave convection drying the reducing sugar was 3.11, 3.36 and 3.86 % i.e. at 40°C, 50°C and 60°C temperature respectively in microwave convective drying. 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 $p \leq 0.01$. Similar behaviour has been observed by Maskan *et al*. (2002) during drying of grape leather (Pestil). Ramesh and Gupta (2005) reported that reducing sugar in pine apple fruit powder and Cholera (2010) reported that reducing sugar in osmo-air guava dried powder and Costa *et al*. (2009) reported that reducing sugar in cashew apple fruit. The results obtained were in agreements with those reported by Hande *et al*. (2014) for convective hot air drying of kokum (*Garcinia indica*) Rind.

6. Total Sugar

Table 4 (f) shows the total sugar of beetroot fruit and slice powder before and after drying at 40°C, 50°C and 60°C temperature respectively in microwave convective 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 increase from 23.01, 23.20 and 24.92% at 40°C, 50°C and 60°C respectively. The increase of total sugar content was significant at $p \leq 0.01$. Similar behaviour has been observed by Hymavathi and Khader (2005) Total sugar in mango powder and Ramesh and Gupta (2005), total sugar content in pine apple powder were ranged between 27.13 to 38.03 %.

7. Colour

Table 4 (h) shows the colour of beetroot slice and slice powder before and after drying at °C, 50°C and 60°C temperature respectively in microwave convective drying. The *L* value of fresh beetroot slices was 27.28±0.07 and after drying it was 26.12 ± 0.03 at 40°C, 25.89 ± 0.02 at 50°C and 25.65 ± 0.05 at 60°C drying temperature. The decrease of colour pigment was significant at $p \leq 0.01$. Similarly before drying a was 31.50±0.85 and after drying it was 28.63 ± 0.08, 28.37 ± 0.25 and 25.65 ± 0.05 at 40°C, 50°C and 60°C temperature respectively. Also for b value of fresh beetroot slices was 9.10±0.16 and after drying it was 9.34 ± 0.02, 10.12 ± 0.03 and 10.37 ± 0.08 at 40°C, 50°C and 60°C temperature respectively.. This variation in colour is due to pigment degradation because of combine effect of microwave-convection dryer.

Co-relation between the objective and subjective scores

For the best treatment, the beetroot slices dried at 60°C temperature in microwave convection drying achieved the desirable qualities i.e. moisture content 6.45 (%), total soluble solid 51.27 (°B), pH 6.30, titratable acidity 0.55 (%), reducing sugar 3.85 (%), total sugar 24.92 (%) and colour value 25.65, 28.08 and 10.37 (*L*, *a* and *b* respectively). Fig. 7 shows the best desirable properties has been observed at 60°C temperature in microwave convection drying.

The best sensory score of the product have been obtained from sensory analysis which was dried at 60°C in microwave convection drying had achieved the highest colour 8.20, flavour 7.82, texture 7.77 and taste 7.93 with overall acceptability 7.91.

From the both Physico-chemical properties, colour measurement and from sensory score the best product i.e. beetroot slices dried at 60°C in microwave convection drying it was concluded that

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
(a)	Moisture %db	520.347±8.36	8.874 ±0.03	6.755±0.01	6.515±0.01
(b)	T.S.S °B	10 ± 2.00	49.17±0.21	50.22±0.10	51.27±0.24
(c)	pH	7.27 ± 0.15	6.12±0.08	6.28±0.03	6.30±0.02
(d)	Titratable acidity %	0.31 ± 0.21	0.86±0.08*	0.62±0.03*	0.55±0.04
(e)	Reducing sugar %	0.29 ± 0.03	3.11±0.03	3.36±0.03	3.86±0.05
(f)	Total Sugar %	18.80 ± 0.56	23.01±0.50	23.20±0.52	24.92±0.37
(g)	Colour *L**	27.28 ± 0.07	26.12±0.03	25.89±0.02	25.65±0.05
	*a**	31.50 ± 0.85	28.63±0.08	28.37±0.25	28.08±0.12
	*b**	9.10 ± 0.16	9.34±0.02	10.12±0.03	10.37±0.08

**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	Colour		
								L	a	b
1	$S.E_m$ (1%)	1.26	0.10	0.03	0.23	0.02	0.02	0.02	0.08	0.03
2	*C.D* (1%)	2.05	0.45	0.13	1.11	0.10	0.11	0.08	0.039	0.12
3	*S.D*	0.74	0.18	0.05	0.46	0.04	0.04	0.03	0.15	0.04
4	$D.f_T$	3	3	3	3	3	3	3	3	3

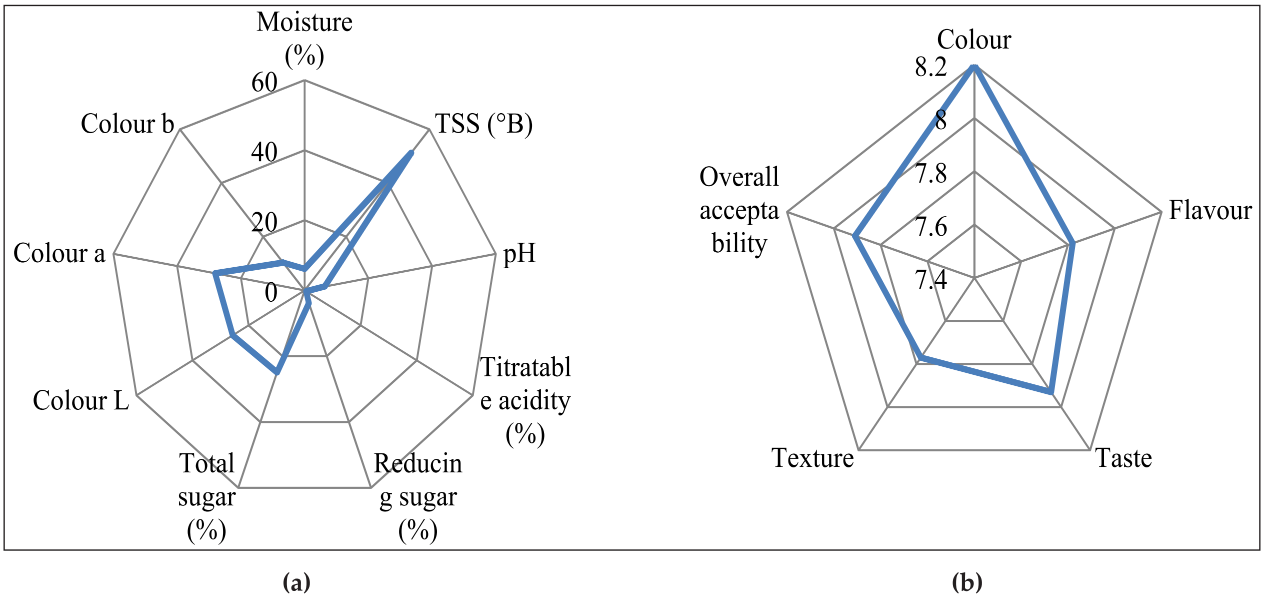

Fig. 7: (a) Physico-chemical properties and **(b)** sensory properties of best treatment of microwave convection drying of beetroot slices

it satisfactorily retains the quality parameter with desirable quality.

CONCLUSION

1. Microwave-convection drying of beetroot slices reduces the moisture from 520.347 ± 8.36 % (db) to 8.87 ± 0.21% (db) at 40°C, 6.75 ± 0.78 at 50°C and 6.51 ± 1.002°C at 60°C. It took around 74 minutes, 60 minutes and 44 minutes for drying of beetroot slices by microwave-convection drying at 40°C, 50°C and 60°C to complete the drying process.

2. The drying rate of beetroot slices were decreased from 5.55 g of water removed / 100 g of bone dry matter per minute to the 0.011 g of water removed / 100 g of bone dry matter per minute, also 6.020 g of water removed /100 g of bone dry matter per minute to the 0.08 g of water removed / 100 g of bone dry matter per minute and 7.98 g of water removed / 100 g of bone dry matter per minute to the 0.023 g of water removed / 100 g of bone dry matter per minute for the drying temperatures of 40°C, 50°C and 60°C respectively.

3. Among the ten models fitted to the experimental data at 40˚C, 50˚C and 60˚C the modified page model was well fitted to the experimental data with $r^2 \geq 0.9910$; $MSE \leq 0.0009$ and chi square (χ^2) ≥0.065.

4. The effective moisture diffusivity values were in the range of 1.6552×10^{-7}, 2.3465×10^{-7} and 3.2131×10^{-7} for 40°C, 50°C and 60°C temperature respectively.

5. Activation Energy needed for the moisture movement from the beetroot slices at 40˚C, 50˚C and 60˚C during microwave-convection drying was found to be 3.672 kJ.mole^{-1}.

6. From the above results it can be concluded that microwave-convection drying technique was an effective treatment to beetroot slices (4 mm) as it reduces the moisture content, drying time and improved the quality of dried sample.

7. There are significantly increase in the total soluble solid from 49.17 ± 0.21 to 51.27 ± 0.24 °B, there are decrease in the titratable acidity of beetroot from 0.86 ± 0.08 to 0.55 ± 0.04 %, The reducing sugar increases from 3.11 ± 0.003 to 3.86±0.05 %, total sugar increases from 23.01 ± 0.50 to 24.92 ± 0.37%, also there was decrease in colour values *L, a, b*, after drying at 40˚C, 50˚C and 60˚C respectively was significant at the $p \leq 0.01$.

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

GENERATIVE AI DECLARATION

The author(s) confirm that there was no use of artificial intelligence (AI)-assisted technology for assisting in the writing or editing of the manuscript, and no images were manipulated using AI. The authors developed and verified all scientific content, data analysis, interpretation of results, and conclusions. The authors take full responsibility for the accuracy, integrity, and originality of the work presented, and no AI tool was listed as an author.

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