International Journal of Food and Fermentation Technology
Citation: *Int. J. Food Ferment. Technol.*, **16**(01): 111-127, June 2026
DOI: 10.30954/2277-9396.01.2026.8

ASSOCIATION FOR AGRICULTURE ENVIRONMENT AND BIOTECHNOLOGY

RESEARCH PAPER

Microwave-Convective Drying of Sapota (*Achras sapota L.*) and its Quality Evaluation

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Paper No.: 351 **Received:** 21-03-2026 **Revised:** 15-05-2026 **Accepted:** 07-06-2026

ABSTRACT

In this paper the peeled ripe sapota slices 5(mm) *kalipatti* variety was exposed for microwave convective drying temperature 20°C, 30°C and 40°C drying took place 54 min, 52 min and 48 min respectively. The quality of dried product i.e. TSS, acidity, pH, reducing sugar, total sugar, carbohydrate, protein, fat, ash and colour (*L*, *a* and *b*) was evaluated. Various drying models i.e. Newton, Pae, Modified Page, Henderson and Pabis, Exponential, Wang and Sing, Thompson Midilli *et al.* Simplified Fick's Diffusion equation, Modified Page equation-II was fitted to the experiment data. The Page model was well fitted to the experimental data on microwave convective drying of sapota slices at 20°C the $k = 0.0024$ $n = 2.1477$ and $R^2 = 0.9904$, MSE = 0.0013 and $\chi^2 = 0.0273$ and 30°C $k = 0.0025$, $n = 2.1234$, $R^2 = 0.9910$, MSE = 0.0014 and $\chi^2 = 0.0257$ and 40°C the $k = 0.0020$, $n = 2.2138$, $R^2 = 0.9914$, MSE = 0.0016 and $\chi^2 = 0.0244$ for all temperatures of the drying. The effective diffusivity value was in the range of 2.26×10^{-7} to 2.7×10^{-7} m^2/s and increases as the drying temperatures from 20°C to 40°C. The activation energy for the drying of sapota slices was 100.9562 kg/mole. The quality parameter was TSS 57.18 to 57.3 (°B); acidity 0.22 to 0.28(%); pH 5.42 to 6.02; reducing sugar 22.03 to 22.94(%); total sugar 31.8 to 33.14(%); carbohydrate 28.3 to 28.7(%); protein 1.45 to 1.53(%); fat 1.55 to 1.65(%); ash 1.47 to 1.57(%) and colour value *L* 66.53 to 66.73; *a* value 8.2 to 8.12; *b* value 27.09 to 27.83 respectively.

Keywords: Microwave convective dying, sapota slices, activation energy etc.

Drying is among the methods for the purpose to produce high quality dried products, which can be consumed directly or used as ingredient for the preparation of chutneys, cakes, muesli, and oat granola. Conventional air-drying has been widely used in industrial drying of food products but this method is energy-intensive and time-consuming and often produces poor quality products. Many authors have reported that this method leads to degradation of products flavour, colour, nutrients, and case hardening, due to their long drying times and high temperatures employed in practice and Hence, combination of advanced drying methods with the conventional hot air is often recommended to reduce long drying times and poor product quality associated with conventional hot air-drying. Combination of osmotic dehydration preceded by microwave-assisted hot air-drying Contreras *et al.* (2008), Vadivambal *et al*. (2009).

Microwave offers advantages that have been employed prior to or with conventional drying in food processing technologies. Several researchers have provided strong evidence that microwave

How to cite this article: Jadhav, S.S. and Swami, S.B. (2026). Microwave-Convective Drying of Sapota (*Achras sapota* L.) and its Quality Evaluation. *Int. J. Food Ferment. Technol.*, **16**(01): 111-127.

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

assisted drying is ideal for fruits and vegetables which speed up drying process, increase mass transfer, and produce good quality products. F. Prothon *et al.* (2001), R. Schiffmann (2001), M. Zhang *et al.* (2006).

Sapodilla, (*Manilkara zapota L.*) which belongs to the family *sapotaceae*, is underutilized tropical fruits commonly known as "sapota" in India and "chiku" in Malaysia. Immature fruits are hard, gummy and rich in tannin (astringent), while the ripe fruits are soft and juicy, with a sweet taste an attractive range colour, which makes them wonderful dessert fruit. (Sallesh, 2016). In India it is grown in an area of 82000 ha with 8 tones production at 14.19 tonnes per hectors productivity. Sapota is grown on a commercial basis in India, the Philippines, Srilanka, Malaysia, Mexico, Venezuela, Guatemala and other Central American countries (Ganjyal *et al*. 2003).

In Maharashtra, Gujarat, Tamilnadu and Karnataka states sapota is grown commercially (Shirol *et al.* 2009). Raw fruits of sapota are astringed, while ripe fruits are sweet. It is mainly used on dessert fruits bedside many processed products are prepared from sapota namely Halwa, Juice, Milk Shake, Shrikhand, fruit Jam. Mature fruits are used for making mixed fruits jams and provide a valuable source of raw materials for manufacture of industrial glucose, protein and natural fruits jellies. They also are canned as slices. (Gopalan *et al*. 1985).

Mature fruit contain about 72 to 78% moisture (wb) and TSS ranges from 12 to 18°brix. The most common cultivars grown are Kalipatti, Chaatri, Dhola Diwani, Long, Bhuri Bhurpatti, Jingar, Venjet, Pala, Cricket ball, Oval, Banglore and Calcutta round. India is the largest producer of sapota followed by Mexico, Guatemala and Venezuela. In the last ten years area under the crop has shown a tremendous increase of over 136 per cent (Maya *et al*. 2003). In India production of sapota was 4.17 thousand hectares during the year 2005-2006 and 4.00 thousands hectares during the year 2010-2011. The growth rate is 4.08% and the production during 2005-2006 is 49.02 thousand tonnes and 43.58 thousand tonnes during 2010-2011. By exporting to different countries about 2.693 thousand tonnes of sapota, India earned about Rs 4, 28, 34,567 in the year of 2011-12.

Sapota fruits is reported to contain sugar, (Siddappa and Bhatia, 1954), acids (Shanmugavelu and Srinivasn, 1973), protein, amino acid (Selvaraj and Pal, 1984), phenolicsviz, galic acid, catechin, chlorogenic acid, leucodelphinidin, and leucodelargonidin and Leucopelargonidin (Matthew and Lakshminarayana, 1969), carotenoids, ascorbic acids, and minerals like potassium, calcium and iron (Selvaraj and Pal, 1984). Fruits contains carbohydrate (50.49 – 100 g), protein (0.7 g – 100g), fat (1.1 g – 100g), fibre (2.6g – 100g), and minerals nutrient viz. calcium (28mg – 100g), iron (2.0mg – 100g), phosphorus (27mg – 100g), ascorbic acid (6.0mg -100g), Golpalan *et al*. (1977).

The present study was undertaken to study the drying characteristics of microwave convective drying of sapota slices. The changes in quality parameters, i.e., acidity, pH, TSS, reducing sugar, non-reducing sugar, protein, fat, carbohydrates, ash and colour of dried sapota slices are also discussed.

MATERIALS AND METHODS

Moisture Content Determination

Sapota fruits were collected from the Dapoli market of fruits was used in one treatment. Under ripe and over ripe fruits were discarded. Fruits were cleaned by removing unwanted portion like leaf and stalk material etc. and then washed in tap water. The cleaned fruits after removing surface moisture were cut into two halves. The seed separated manually. Initial moisture content of the sapota was calculated by using hot air oven at 105°C±1 for 24 h. The final weight of sapota slices after 24 h was recorded. The moisture content of the sapota slices was determined by following formula (Chakraverty, 1994).

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

Where,

W_1 = weight of sample before drying, gram

W_2 = weight of bone dried sample, gram

Experimental Setup

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 (20, 30 and 40°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 SFP cubes was determined and 100 g were taken in 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 roter. After achieving the set point temperature the sapota 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 20°C, 30°C and 40°C 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 3 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 sapota slices were then transferred into low density polyethylene 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 water per g dry matter per hour), moisture ratios (MR) and final moisture content of the sapota slices were also recorded. Three replications were taken for each experiment. A schematic of the microwave convective dryer is presented in Fig 1. Figure 1 shows the microwave convective dryer system used for the experimentation.

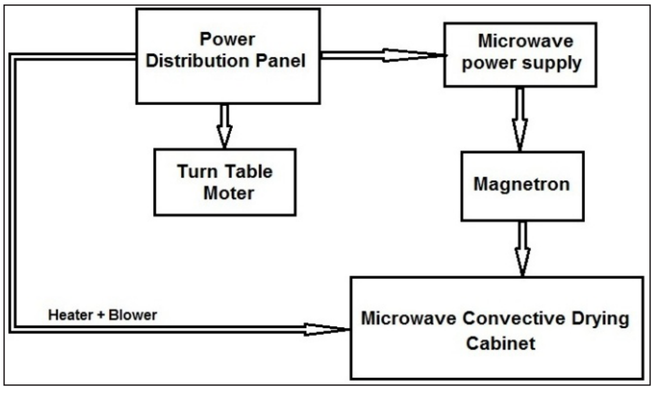

Fig. 1: Schematic of microwave convective dryer

Drying Characteristics

Moisture content (% db) versus drying time (min) and drying rate (kg of water/100 g dry solid/min) with respect to moisture content were determined for each day during microwave convective drying of sapota slices. Moisture ratio versus drying time (min) was also determined from the experimental data. Various mathematical models listed in Table 1 were tested on the experimental data on moisture ratio versus drying time in minutes of dried sapota slices with solar drying. The moisture ratio is usually expressed as,

$$MR = \frac{M - M_C}{M_0 - M_C} \quad \ldots(2)$$

Where

MR = Moisture ratio

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

M_e = EMC, % (db)

M_0 = Initial moisture content, % (db)

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).

Table 1: Mathematical model tested with the moisture ratio of sapota slices

Sl. No.	Model	Equation	References
1	Newton	$MR = exp\ (-kt)$	Westerman *et al.* (1973)
2	Page	$MR = exp\ (-kt^n)$	Page (1949)
3	Modified Page	$MR = exp\ (-kt^n)$	Overhults *et al.* (1973)
4	Henderson and Pabis	$MR = a\ exp\ (-kt)$	Westerman (1973)
5	Exponential	$MR = exp\ (-kt)$	Liu and Bakker (1997)
6	Wang and Sing	$MR =1+at+bt^2$	Wang and Singh (1978)
7	Thompson	$MR = \alpha\ exp\ (-kt^n) + bt$	Sacilik *et al.* (2006)
8	Midilli *et al.*	$MR= a\ exp\ (-kt^{n)} + bt$	Midilli *et al.* (2002)
9	Simplified Fick's Diffusion equation	$MR = a\ exp\ (-k\ (t\ /\ L^2))$	Diamente and Munro (1991)
10	Modified Page equation-II	$MR= exp\ (-(kt)n)$	Zhang and Litchfield (1991)

Non-linear regression analysis was performed to the experimental data by using SAS 6.0. The higher value of co-relation coefficient (r) and lower value of $RMSE$ (Root Mean Square Error) indicate that the model is best fitted to the experimental data (Togrul and Pehlivan, 2004). These parameters were calculated by using equations, N and n are the number of observations and the number of constants respectively,

$$RMSE = \left[\frac{1}{N}\sum_{i=1}^{n}\left(MR_{\exp} - MR_{pre}\right)^2\right] \quad \ldots(3)$$

Where,

MR_{exp} = experimental moisture ratio

MR_{Pre} = predicted moisture

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 root mean square error ($RMSE$). The higher the r^2 value and lower the chi-square (χ^2) and RMSE values, the better are the goodness of fit (Ozdemir and Devers, 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:-

$$\chi^2 = \frac{\sum_{i=1}^{N}\left(MR_{\exp.i} - MR_{pre.i}\right)^2}{N - Z} \quad \ldots (4)$$

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.

In this study, the non-linear regression analysis was performed by using the..

Calculation of Effective Diffusivity

Effective diffusivity was calculated by using Fick's Second law of diffusion (Doymaz, 2004) as given in equation. This equation assumes that effective diffusivity is constant and shrinkage of the sample is negligible.

$$\frac{\partial M}{\partial t} = D_{eff}.\nabla^2 M \quad \ldots(5)$$

Where,

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

t = is the time / s

D_{eff} = effective moisture diffusivity, m^2/s.

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:

$$MR = \frac{8}{\pi^2}\sum_{i=}^{n}\frac{1}{(2n-1)^2}\exp\left(\frac{-(2n-1)2\pi^2 D_{eff} t}{4H^2}\right) \quad \ldots(6)$$

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:

$$In(MR) = In\frac{8}{\pi^2} - \frac{\pi^2 D_{eff} t}{4l^2} \quad \ldots(7)$$

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.

$$\text{Slope} = \frac{\pi^2 D_{fee}}{4L^2} \quad \ldots(8)$$

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 6). 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.

$$D_{eff} = D_0 Exp\left(\frac{-E_a}{R(T+237.15)}\right) \quad \ldots(9)$$

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;

$$InD_{eff} = InD_0 - \frac{E_a}{R(T+273.15)} \quad \ldots(10)$$

Energy of activation can thus be calculated from Equation (10), 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).

Evaluation of Quality Parameters for the Dried Product

Total soluble solids (° B)

A total soluble solid sapota slices before drying and after drying by microwave convective drying was determined 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 sapota slices was determined. The experiment was replicated three times.

Acidity (%)

The Titratable acidity of sapota slices before drying and after drying by microwave convective 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 replication were carried out and the average reading was reported.

$$\text{Titratable acidity (\%)} = \frac{N \times T \times E}{W \times V \times 1000} \times 100 \quad \ldots(11)$$

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

pH

pH of sapota slices before drying and after drying by microwave convective 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 sapota slices was taken in beaker, and then the tip of electrode and temperature probe was then submerging in to the sample. The pH reading display on the primary LCD and temperature on secondary one. The pH of fresh sapota slices was determined for three replication.

Reducing sugars (%)

The reducing sugar of sapota slices before drying and after drying by microwave convective drying was estimated by using Lane and Eynon Method with modifications suggested by Ranganna (1997). A known weight of sapota 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 =

$$\frac{100}{\text{Buttereading}} \times \frac{\text{Volume prepared}}{\text{Inital volume}} \times \quad \ldots(12)$$
$$Gv \text{ off chlings soln.}$$

Where,

GV = Glucose value.

Total sugars (%)

Total sugars sapota slices before drying and after drying by microwave convective drying was estimated 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. 13). The experiment was repeated three times to get the replication.

Total sugar =

$$\frac{\text{Factor } \times \text{Dilution}}{\text{Titer reading} \times \text{weight of sample}} \times 100 \quad \ldots(13)$$

Carbohydrates (%)

The carbohydrate of sapota slices before drying and after drying by microwave convective drying was estimated by anthrone method in which prepared a series of Glucose solution and distilled water in the ratio (0:1; 0.2:0.8; 0.4:0.6; 0.6:0.4; 0.8:0.2; and 1:0) by using spectrophotometer. One gram ground sapota pulp was mixed with 5 ml of 2.5 N HCL and then heated for 3 h in water bath. The mixture was allowed to cool for 1.3 h, and it is added with sodium carbonate till effervescence stops. It is seen by naked eyes. After filtration, anthrone reagent (2 g anthrone powder 100 ml H_2SO_4) was added in filtered solution. The mixture was heated for 8 min and allowed to cool. The solution was taken in the curvetted of spectrophotometer, and absorbance was recorded at 630 nm. A graph was plotted, i.e., absorbance versus concentration (glucose stock: distilled water), and concentration of unknown sample was measured by using formula,

Concentration % =

$$\frac{\text{Absorbance of unknown} - \text{Concentration of standard}}{\text{Absorbance of standard}} \quad \ldots(14)$$

Protein (%)

The protein content of sapota slices before drying and after drying by microwave convective drying was determined by Lowry's Method (Lowry *et al.* 1951) using spectrophotometer (Make: Systronics-UV Visible spectrophotometer; Ahmadabad; Model No: 106). In this method, 1 g sapota pulp was mixed with 5 ml of alkaline solution which was prepared from 50 ml of Part one (2% sodium carbonate in 0.1 N NaOH) solution and 1 ml of part two (0.5% copper sulphate in 1% sodium potassium tartarate) solution. Mixed solution i.e. part one and part two was rapidly diluted with folin-ciocalteu reagent. After 30 min, sample was loaded in the cuvet of spectrophotometer up to>3/4 of its level. The absorbance was read against standard protein solution at 750nm. Absorbance is recorded as protein content.

Fat (%)

Fat of sapota slices before drying and after drying by microwave convective drying was determined using soxhlet fat extraction system (AOAC, 2010) by using Soxhlet apparatus (Make: Elico, Hyderabad). In this method, initially weight of empty flask was weighed. 2 g sapota pulp wrapped in filter paper was siphoned for 9-12 times with the petroleum ether in soxhlet apparatus. After removing assembly, evaporation of petroleum ether was allowed by heating. Residue remained at the bottom of the flask and was reweighed with flask. The quantity of residue was determined as fat content of sapota powder.

Ash (%)

Ash percentages of the sapota slices before drying and after drying by microwave convective drying were determined by using the procedure as described (AOAC, 2000). 2 g of the dried sapota powder sample was weighed accurately in the crucible. The crucible was heated gently on a burner for 5 min at first and then strongly in a muffle furnace at 550 ± 20°C for 2 hours, till grey ash was obtained. Cool the crucible in desiccators and weigh. The % ash (w/w) was calculated by using following equation (15).

$$\frac{\text{Weight of sample portion, g} - \text{weight loss on ashing, g}}{\text{Weight of sample portion, g}} \times 100 \qquad \ldots(15)$$

Colour

The dried grounded sapota slices before drying and after drying by microwave convective drying 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. Around 20 g dried sapota 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).

RESULTS AND DISCUSSION

Drying Kinetics

Fig. 3 shown change in moisture content (db) % w.r.t. time (min) of sapota dried slices by microwave convective drying is at the sapota dried slices from an initial moisture content of 20°C 324.268 (%db) these slices were dried to final moisture content of 9.432 (% db) It took around 58 min for drying of sapota slices at 30°C 324.268 (%db) to 9.722 in 54 min and 40°C 324.268 (% db) to 9.398 (% db) in 48 min to complete the microwave convective drying process.

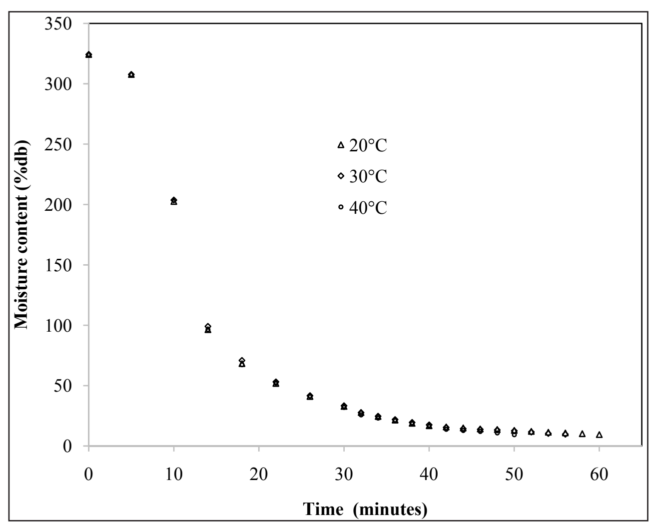

Fig. 3: Moisture content (%db) w.r.t.time (min) for Microwave convective dryng of sapota slices

Fig. 4 shown in drying rate (kg water / 100 g dry bone material / min) versus moisture content % (db) of sapota slices by Microwave convective drying at 20°C drying rate 15.275 to 0.233, 30°C drying rate at 18.958 to 0.1863 and 40°C 19.79 to 0.235 respectively this increase in drying rate because of the increased heat transfer potential between the air and sapota slices which favours the evaporation of water from sapota 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. And the drying rate generally decreased as pulse ratio increased. A constant drying rate period was not observed in the drying of dill level at continuous microwave-convective drying. An absence of constant drying period indicates that moisture removal, which is driven internally by microwave energy absorption, takes places only in the falling rate period. Similar results were obtained for continuous microwave drying of potato (Wang *et al.* 2004), banana (Maskan 2000), leek (Dadali and Ozbek 2008), garlic (Sharma and Prasad 2001) and parsley (Soysel *et al*. 2006).

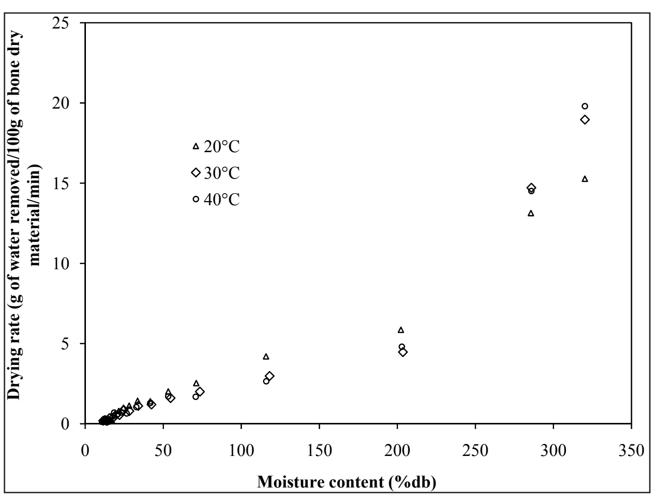

Fig. 4: Drying rate (g water removed/100g bone dry material/,min) versus moisture content%(db) of sapota slices by Microwave convective drying

Fig. 5 shows the moisture ratio with respect to time (min) drying Microwave convective drying of sapota slices in at 20°C, 30°C and 40°C. And moisture ratio decreases from 1 to 1.16×10^{-6} at 20°C, moisture ratio decreases 1 to 5.81×10^{-7} at 30°C and at 40°C moisture ratio decreases from 1 to 2.92×10^{-7} respectively.

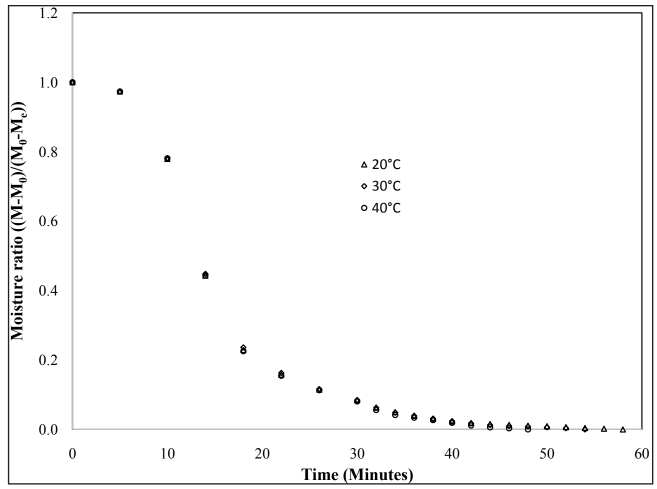

Fig. 5: Effect of temperature of drying on the Moisture ratio of Microwave convective dried of Sapota Slices

Table 2 (a,b,c). Shows the value of drying constants, R^2, and RMSE of different models fitted to the experimental data on microwave convective drying of sapota slices i.e. Newton, modified page, Henderson and Pabis, exponential, Wang and Sing, Thompson, Midilli *et al.* Simplified Fick's Diffusion (SFFD) equation and Modified Page equation-II model. Out of these models Page model was well fitted to the experimental data on microwave convective drying of sapota slices at 20°C, k = 0.0024 n = 2.1477 and R^2 = 0.9904, MSE = 0.0013 and χ^2 = 0.0273 and 30°C k = 0.0025, n = 2.1234, R^2 = 0.9910, MSE = 0.0014 and χ^2 = 0.0257 and 40°C k = 0.0020, n = 2.2138, R^2 = 0.9914, MSE = 0.0016 and χ^2 = 0.0244.

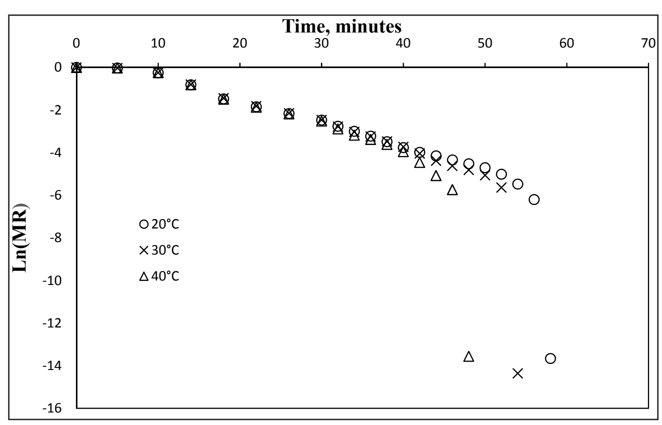

Fig. 6: Ln(MR) versus time, min for effective diffusivity for Sapota slices dried by Microwave convective drying

Table 2 (a): Microwave convective drying temperature (20°C)

Sl. No.	Model Name	Temperature 20°C			
		Model Parameter	**R^2**	**MSE**	**χ^2 (Chi Square)**
1	Newton	k = 0.0667	0.9379	0.0084	0.1774
2	Page	k = 0.0024; n = 2.1477	0.9904	0.0013	0.0273
3	Modified Page	k = 0.0608; n = 2.1477	0.9904	0.0013	0.0273
4	Henderson and Pabis	a = 1.1666; k = 0.0742	0.9524	0.0068	0.1361
5	Exponential	k = 0.0667	0.9379	0.0084	0.1774
6	Wang and Sing	a = -0.044471826 b = 0.000484770	0.9634	0.0052	0.1044
7	Thompson	a = -5.861668134 b = -0.294347746	0.9971	4.5250	9.05005E+01
8	Midilli *et al.*	a = 1.0324; k = 0.0025 n = 2.1589; b = 0.0004	0.9928	0.0011	0.0204
9	Simplified Fick's Diffusion (SFFD) equation	a = 1.1666; c = 0.1016 L = 1.1705	0.9524	0.0068	0.1361
10	Modified Page equation-II	k = 1.3953; L = 4.3822 n = 2.1477	0.99043	0.0013	0.0273

Table 2 (b): Microwave convective drying temperature (30°C)

Sl. No.	Model Name	Temperature 30°C			
		Model Parameter	**R^2**	**MSE**	**χ^2(Chi Square)**
1	Newton	k = 0.0663	0.9382	0.0093	0.1773
2	Page	k = 0.0025; n = 2.1234	0.9910	0.0014	0.0257
3	Modified Page	k = 0.0603; n = 2.1234	0.9910	0.0014	0.0257
4	Henderson and Pabis	a = 1.1671; k = 0.07383	0.9527	0.0075	0.1357
5	Exponential	k = 0.06638	0.9382	0.0093	0.1773
6	Wang and Sing	a = -0.045315392 b = 0.000508010	0.9665	0.0053	0.0959
7	Thompson	a = -5.722221984 b = -0.285461670	0.9964	4.9929	8.98737E+01
8	Midilli *et al.*	a = 1.0000; k = -6.2399 n = 5.17874E+01; b = 0.0016	0.3725	0.1001	1.8020
9	Simplified Fick's Diffusion (SFFD) equation	a = 1.1671; c = 0.1030; L = 1.1815	0.9527	0.0075	0.1357
10	Modified Page equation-II	k = 2.0853; L = 4.8414; n = 2.1234	0.9910	0.0014	0.0257

Table 2 (c): Microwave convective drying temperature (40°C)

Sl. No.	Model Name	Temperature 40°C			
		Model Parameter	**R^2**	**MSE**	**χ^2 (Chi Square)**
1	Newton	k = 0.0669	0.9358	0.0114	0.1830
2	Page	k = 0.0020; n = 2.2138	0.9914	0.0016	0.0244
3	Modified Page	k = 0.0611; n = 2.2137	0.9914	0.0016	0.0244
4	Henderson and Pabis	a = 1.1675; k = 0.0746	0.9503	0.0094	0.1416

5	Exponential	$k = 0.0669$	0.9358	0.0114	0.1830
6	Wang and Sing	$a = -0.0467$; $b = 0.0005$	0.9662	0.0064	0.0964
7	Thompson	$a = -5.4940$; $b = -0.2937$	0.9925	8.5676	1.28515E+02
8	Midilli *et al.*	$a = 1.0000$; $k = -6.7325$ $n = 5.02412E+01$; $b = 0.0022$	0.3806	0.1178	1.7683
9	Simplified Fick's Diffusion (SFFD) equation	$a = 1.1675$; $c = 0.0978$; $L = 1.1453$;	0.9503	0.0094	0.1416
10	Modified Page equation-II	$k = 1.7077$; $L = 4.5617$; $n = 2.21379$	0.9914	0.0016	0.0244

Fig. 6 shows the Ln(MR) versus time, minutes for effective diffusivity for sapota slices in dried by microwave convective drying at 20°C,30°C and 40°C temperature.

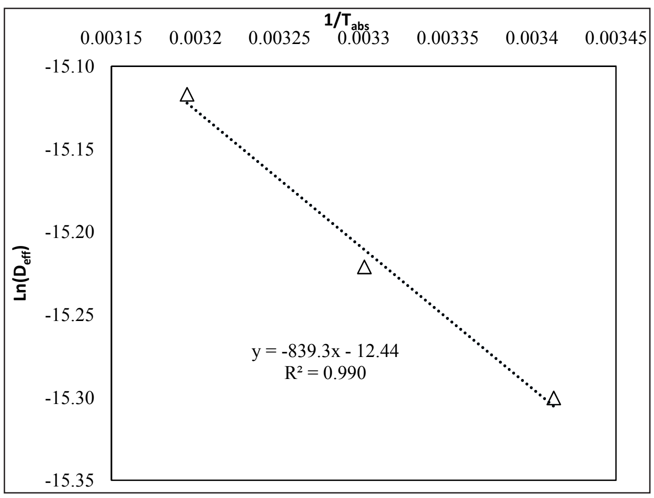

Fig. 7: Ln(Deff) versus 1/Tabs of Microwave convective drying of Sapota slices

Effective diffusivity for sapota slices dried by Microwave convective drying. And the three temperatures are performing in this table 20°C, 30°C and 40°C. Table 3 values of Effective Diffusivity attained for various treatments of Sapota slices dried by Microwave connective drying. And value y = -839.38x – 12.441 and $R^2 = 0.9905$.

Table 3: Drying temperature with Effective Diffusivity

Drying Temperature	Effective Diffusivity (D_{eff}) × 10^{-7} (m^2/s)
20°C	2.26
30°C	2.45
40°C	2.7

In microwave convective drying the effective diffusivity at temperature 20°C, 30°C and 40°C is 2.26×10^{-7}, 2.45×10^{-7} and 2.72×10^{-7} (m^2/s) respectively. The effective diffusivity was in the range of 1.973×10^{-10} to 8.059×10^{-11} for fig fruits (Doymaz *et al.* 2011), 3.2×10^{-9} m^2/s to 11.2×10^{-9} m^2/s for red bell pepper (Vega *et al.* 2007), and 4.76×10^{-9} to 8.32×10^{-9} m^2/s for apricot at 50°C, 60°C, 70°C and 80°C. (Togrul and Pehivan, 2003). 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). Marinos-Kouris and Maroulis (1995) for food materials. Srikiten and Roberts (2003) also reported the moisture diffusivity range for potato, carrot core, carrot cortex and apple as 1.2×10^{-9} to 9.92×10^{-8} m^2/s. over the range 50°C to 80°C. In mango slices microwave convective drying moisture diffusivity 1.45×10^{-9} to 1.84×10^{-9} Ernest (2015).

The effective moisture diffusivity was calculated using the slope methods as indicated the slope equation and value obtained for different drying methods for pineapple varied from 6.89×10^{-10} to 5.1×10^{-10} for (microwave drying at 700w) these values were generally within the range of 10×10^{-11} to 10×10^{-11} m^2/s gives for food materials (Maskan *et al.* 2002; Aghbaslo *et al.* 2008).

Table 4: Pre-Exponential factor D_0 of Arrhenius equation and the activation energy E_a (KJ/mole) at varied temperature of sapota sliced dried by convective hot air drying

$D_0 \times 10^{-6}$ (m^2/s)	E_a (kJ/mole)
3.95314	100.9562

Table 3 denoted the Arrhenius equation value is D_0 = 3.953 and activation energy Ea (KJ/mole) at 100.9562. Albanese *et al.* (2006) $D_0 = 8.56501 \cdot 10^{-7}$ m^2/s, E_0 = 19089.7 J/mole Potatoes Slices. The effective diffusivity Fig. 2. 47×10^{-10} (Doymaz, 2005), Pineapple of microwave drying effective diffusivity 6.89×10^{-11} (Olanipeckun *et al.* 2015), Seedless and Seeded Grapes. 1.02×10^{-11} and 1.66×10^{-11} m^2/s. Similar type's results are in pineapple activation energy 6.706×10^{-9} the E_a Values obtained were 12.46 KJ/mol for microwave drying. These E_a values are within the general range of 12.7-110 KJ/mol for food materials (Aghbashlo 2008).

Evaluation of quality parameters for the sapota dried product

1. Moisture (% wb)

Table 5 (a) shows the Moisture content sapota slices before drying and after drying at 20°C, 30°C, and 40°C by microwave convective drying. The moisture content of sapota slices before drying was 75.2(% wb). The moisture content of sapota slices were 9.43, 9.7 and 9.3 (% wb) at 20°C, 30°C, and 40°C respectively.

Table 6 (a) shows the ANOVA for effect of temperature on moisture content of sapota slices after drying at 20°C, 30°C, 40°C by microwave convective drying. It was observed that the decrease the moisture content with increases in temperature was significant at 0.05).

2. TSS °B

Table 5 (b) shows the TSS of sapota slices before drying and after drying at 20°C, 30°C, and 40°C by microwave convective drying. The TSS of sapota slices before drying was 19.45°C and it increases after drying from 57.18°B to 57.37 °B. As the temperature of drying increases from 20°C to 40°C the TSS of sapota slices increases from 57.18, 57.21 and 57.37 °B. The TSS of dried sapota slices were at 20°C, 30°C and 40°C drying temperature respectively.

Table 6 (b) shows the ANOVA for the TSS of sapota slices at varied temperature 20°C, 30°C and 40°C. The increases in total soluble solid of sapota slices after microwave convective 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 TSS w.r.t increase in drying temperature was significant at 0.05). Gunjyal *et al.* (2005) reported the TSS of sapota slices was in the range of 22 to 28 °B.

3. Acidity (%)

Table 5 (c) shows the acidity of sapota slices before drying and after drying at 20°C, 30°C, and 40°C by microwave convective drying. The acidity of sapota slices before drying was 0.16 %. As the temperature of drying increases from 20°C to 40°C the acidity increases from 0.22 to 0.28 %. The acidity of sapota slices were 0.22, 0.26 and 0.28 at 20°C, 30°C, and 40°C respectively. As the temperature of drying increases the acidity increases.

Table 6(c) shows the ANOVA for effect of temperature on acidity of sapota slices after drying at 20°C, 30°C, and 40°C by microwave convective drying. It was observed that the increases the acidity with increases in temperature was significant at 0.05). Abul Fadl, (2015) reported the Fig fruit slices acidity was in the range of 0.35 %, Ridha, (2012) reported the Tomato slices in microwave drying acidity range was 5.56 to 5.84 %.

4. pH

Table 5(d) shows the pH of sapota slices before drying and after drying at 20°C, 30°C, and 40°C by microwave convective drying. The pH of sapota slices before drying was 5.39. As the temperature of drying increases from 20°C to 40°C the pH increases from 5.39 to 6.02. The pH of sapota slices were 5.39, 5.72 and 6.02 at 20°C, 30°C, and 40°C respectively. As the temperature of drying increases the pH increases.

Table 6 (d) shows the ANOVA for effect of temperature on pH of sapota slices after drying at 20°C, 30°C and 40°C by microwave convective drying. It was observed that the increases the pH with increases in temperature was significant at 0.05). Ridha, (2012) reported the pH of Tomato in microwave drying range was 4.53 to 4.57.

5. Reducing sugar (%)

Table 5(e) shows the reducing sugar of sapota slices before drying and after drying at 20°C, 30°C, and 40°C by microwave convective drying. The reducing sugar of sapota slices before drying was 16.3 %. As the temperature of drying increases from 20°C to 40°C the reducing sugar increases from 22.03 to 22.94 %. The reducing sugar of sapota slices were 22.03, 22.49 and 22.94 at 20°C, 30°C, and 40°C respectively. As the temperature of drying increases the reducing sugar increases.

Table 6(e) shows the ANOVA for effect of temperature on reducing sugar of sapota slices after drying at 20°C, 30°C, and 40°C by microwave convective drying. This increase in reducing sugar might be attributed due to concentration of fruit flavours and mass/solids during drying. It was observed that the increase the reducing sugar with increases in temperature was significant at 0.05). Abul Fadl, (2015) reported the Fig slice in microwave drying reducing sugar was in the range is 0.35 %.

6. Total sugar (%)

Table 5(f) shows the total sugar of sapota slices before drying and after drying at 20°C, 30°C, and 40°C by microwave convective drying. The Total sugar of sapota slices before drying was 48.50 %. As the temperature of drying increases from 20°C to 40°C the Total sugar increases from 31.8to 33.14 %. The non-reducing sugar of sapota slices were 31.8, 32.12 and 33.14 at 20°C, 30°C, and 40°C respectively. As the temperature of drying increases the total sugar increases.

Table 5 (f) shows the ANOVA for effect of temperature on Total sugar of sapota slices after drying at 20°C, 30°C, and 40°C by microwave convective drying. It was observed that the increases the total sugar with increases in temperature were significant at 0.05).

8. Carbohydrate (%)

Table 5 (g) shows the carbohydrate of sapota slices before drying and after drying at 20°C, 30°C, and 40°C by microwave convective drying. The carbohydrate of sapota slices before drying was 19.50%. As the temperature of drying increases from 20°C to 40°C the carbohydrate increase from 28.3 to 28.7 %. The carbohydrate of sapota slices were 28.3, 28.4 and 28.7 at 20°C, 30°C, and 40°C respectively. As the temperature of drying increases the carbohydrate increases.

Table 5 (g) shows the ANOVA for effect of temperature on carbohydrate of sapota slices after drying at 20°C, 30°C, and 40°C by microwave convective drying. It was observed that the increases the carbohydrate with increases in temperature was significant at 0.05). Abul Fadl, (2015) reported the Fig fruit slices in microwave drying carbohydrate content was in the range is 24.64 % and Ernest Abano, (2016) reported the mango slices drying carbohydrate content was in the range is 27.2 %.

9. Protein (%)

Table 5 (h) shows the protein of sapota slices before drying and after drying at 20°C, 30°C, and 40°C by microwave convective drying. The protein of sapota slices before drying was 0.5 %. As the temperature of drying increases from 20°C to 40°C the protein increase from 1.45 to 1.53 %. The protein of sapota slices were 1.45, 1.49 and 1.53 at 20°C, 30°C, and 40°C respectively. As the temperature of drying increases the protein increases.

Table 5 (h) shows the ANOVA for effect of temperature on protein of sapota slices after drying at 20°C, 30°C, and 40°C by microwave convective drying. It was observed that the increases the protein with increases in temperature was non-significantly at 0.05). Abul Fadl, (2015) reported the Fig fruit slices in microwave drying protein content was in the range is 1.68 %, Ernest Abano, (2016) reported the mango slices drying protein content was in the range is 1.33 (%).

10. Fat (%)

Table 5 (i) shows the fat of sapota slices before drying and after drying at 20°C, 30°C, and 40°C by microwave convective drying. The protein of sapota slices before drying was 0.49 (%). As the temperature of drying increases from 20°C to 40°C the fat increases from 1.55 to 1.65 (%). The fat of sapota slices were 1.55, 1.59 and 1.65 at 20°C, 30°C, and 40°C respectively. As the temperature of drying increases the fat increases.

Table 5 (i) shows the ANOVA for effect of temperature on fat of sapota slices after drying at 20°C, 30°C, and 40°C by microwave convective drying. It was observed that the increases the fat with increases in temperature was significant at 0.05). Ernest Abano (2016) reported the Mango slices drying fat content were in the range is 1.51 (%).

11. Ash %

Table 5 (j) shows the ash of sapota slices before drying and after drying at 20°C, 30°C, and 40°C by microwave convective drying. The ash of sapota slices before drying was 0.47(%). As the temperature of drying increases from 20°C to 40°C the ash increase from 1.47 to 1.57 (%). The ash of sapota slices were 1.47, 1.51 and 1.57 at 20°C, 30°C, and 40°C respectively. As the temperature of drying increases the fat increases.

Table 5 (j) shows the ANOVA for effect of temperature on Ash of sapota slices after drying at 20°C, 30°C, and 40°C by microwave convective drying. Ash is the inorganic residue remaining after the water and organic matter have been removed by heating in a food. The ash content is a measure of the total amount of minerals present within a food. The increase in the ash contents observed in this study could be as a result of the removal of moisture which tends to increase the concentration of nutrients Morris *et al.* (2004). It was observed that the increases the ash with increases in temperature was significant at 0.05). Abul Fadl (2015) reported the fig a fruit slice in microwave drying ash content was in the range is 1.24 (%).

12. Colour

Table 5 (k) shows the colour value L of sapota slices before drying and after drying at 20°C, 30°C, and 40°C by microwave convective drying. The colour value of L sapota slices before drying was 71.10. As the temperature of drying increases from 20°C to 40°C the colour value L of increases from 66.53 to 66.73. The colour value of L sapota slices were 66.53, 66.68 and 66.73 at 20°C, 30°C, and 40°C respectively. As the temperature of drying increases the colour value *L* increases.

Table 5 (k) shows the colour value a of sapota slices before drying and after drying at 20°C, 30°C, and

Table 5: Chemical composition of sapota slices before and after microwave convective drying

Sl. No.	Chemical constituents	Before drying	After drying 20°C	After drying 30°C	After drying 40°C	S.E (5%)	C.D (5%)
1	(a) Moisture (% wb)	75.2±1.6	9.43 ±0.18	9.7 ±0.2	9.3 ±0.02	0.02	0.0
2	(b) TSS (°Brix)	19.45±1.40	57.18± 0.35	57.21± 0.16	57.37±0.64	0.03	0.10
3	(c) Acidity (%)	0.16 ±0.14	0.22 ± 0.01	0.26 ± 0.01	0.28 ± 0.01	0.01	0.04
4	(d) pH	5.39 ±0.14	5.39± 0.52	5.72 ± 0.01	6.02± 0.53	0.01	0.05
5	(e) Reducing sugar (%)	16.3 ±1.23	22.03 ± 0.64	22.49± 0.42	22.94 ± 0.17	0.02	0.06
6	(f) Total sugar (%)	48.50 ±1.58	31.8 ± 0.79	32.12± 0.36	33.14 ± 1.00	0.06	0.20
7	(g) Carbohydrate (%)	19.50 ±3.47	28.3±0.1	28.4±0.1	28.7±0.1	0.03	0.10
8	(h) Protein (%)	0.5±0.13	1.45±0.8	1.49±0.8	1.53±0.8	0.01	0.02
9	(i) Fat (%)	0.49±0.44	1.55±0.1	1.59±0.1	1.65±0.1	0.02	0.04
10	(j) Ash (%)	0.47±0.03	1.47±0.1	1.51±0.2	1.57±0.2	0.01	0.02
11	(K) Colour L	71.10±2.43	66.53± 0.03	66.68 ± 0.12	66.73± 0.15	0.01	0.03
	A	7.14±0.02	8.2± 0.18	8.9 ± 0.06	8.12 ± 0.04	0.01	0.14
	B	40.50±0.03	27.09±0.02	27.40 ± 0.03	27.83 ± 0.09	0.07	0.23

(Sig= significant and Non sig= non-significant at p ≤ 0.05).*

40°C by microwave convective drying. The colour value of a sapota slices before drying was 7.14. As the temperature of drying increases from 20°C to 40°C the colour value a of increases from 8.2 to 8.12. The colour value of a sapota slices were 8.02, 8.09 and 8.12 at 20°C, 30°C, and 40°C respectively. As the temperature of drying increases the colour values a increases.

Table 5 (k) shows the colour value b of sapota slices before drying and after drying at 20°C, 30°C, and 40°C by microwave convective drying. The colour value of b sapota slices before drying was 40.50. As the temperature of drying increases from 20°C to 40°C the colour value b of increases from 27.0 to 27.83. The colour value of b sapota slices were 27.9, 27.40 and 27.83 at 20°C, 30°C, and 40°C respectively. As the temperature of drying increases the colour value b increases.

Table 5 (k) shows the ANOVA for effect of temperature on colour value L and colour b of sapota slices after drying at 20°C, 30°C, and 40°C by microwave convective drying. It was observed that the increases the colour value L and b with increases in temperature was significant at 0.05). And shows the ANOVA for effect of temperature on colour value a colour of sapota slices after drying at 20°C, 30°C, and 40°C by microwave convective drying. It was observed that the increases the colour value a with increases in temperature was non-significantly at 0.05). This variation in colour is due to pigment degradation because of long drying duration.

CONCLUSION

Moisture content (db) % w.r.t. time (min) of sapota dried slices by Microwave convective drying is at the sapota dried slices from an initial moisture content of 20°C 324.268 % (db) to 9.43 % (db) It took around 58 min for drying of sapota slices, 30°C 324.268 % (db) to 9.72 in 54 min and 40°C 324.268 % (db) to 9.39 % (db) in 48 min to complete the drying process.

Page model well fitted in these drying experiment in microwave drying at 20°C k = 0.0024, n = 2.1477 and R^2 = 0.9904, MSE = 0.0013 and χ^2 = 0.0273 and 30°C k = 0.0024, n = 2.1234, R^2 = 0.9910, MSE = 0.0014 and χ^2 = 0.0257 and 40°C k = 0.0020, n = 2.2138, R^2 = 0.9914, MSE = 0.0016 and χ^2 = 0.0244.

Moisture content in before drying was sapota slices is 75.2 (wb). and after microwave convective drying 20°C, 30°C, 40°C are 9.43 (wb) , 9.7 (wb) and 9.3(wb), Acidity of sapota slices in before drying is 0.16. And after microwave convective drying 20°C, 30°C, Reducing sugar of fresh sapota slices is 16.3. And after microwave convective drying 20°C to 40°C is increasing 22.03 to 22.94 %. 40°C is increasing acidity 0.22, 0.26 and 0.28 % respectively, pH of sapota slices before drying was 5.39 and after microwave convective drying 20°C to 40°C is increasing 5.39 to 6.02, reducing sugar of fresh sapota slices is 16.3. And after microwave convective drying 20°C to 40°C is increasing 22.03 to 22.94 %.

Total sugar of sapota slices is 48.50 % and after microwave convective drying 20°C to 40°C is decreasing 31.8 to 33.14 %, The TSS of sapota slices is before drying 19.45 and after dying microwave convective drying 20°C to 40°C is increasing 57.18 to 57.37, Carbohydrate of sapota slices in before drying 19.50. And after dying increases in microwave convective at 20°C to 40°C. 28.3 to 28.7 %, Protein content of sapota slices in before drying 0.5 and the after drying of sapota slices in microwave convective at 20°C to 40°C in 1.45 to 1.53 %, Fat content of sapota slices in before drying 0.49 and fat in after drying slices dying in microwave convective at 20°C, 30°C, and 40°C increases in 1.55 to 1.65 %, Ash of sapota slices in before frying 0.47% and after drying in microwave convective at 20°C to 40°C increases 1.47 to 1.57 %.

Colour of sapota slices before drying was 71.10 (*L*, *a*, *b* respectively) and after microwave convective drying at 20, 30 and 40°C. L value was 66.53, 66.68 and 66.73 and a value of colour 8.2, 8.9 and 8.9. And b value of sapota slices 27.09, 27.40 and 27.83. Colour of sapota slices after microwave convective drying L, a and b value also increases at the temperature 20°C, 30°C and 40°C.

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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