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Research Paper

Evaluation of Solar Drying Characteristics of Sapota Slices and its Quality Evaluation

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ABSTRACT

In this paper the peeled ripe sapota slices 5(mm) of *kalipatti* verity was exposed for solar drying. And this experiment drying took place 59 h for drying of sapota slices. It took around 6 days to complete the drying process. 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, Page, Modified Page, Exponentials, Thompson, Modified Page equation was fitted to the experiment data. Page model was well fitted in this experiment. The parameter of Page model are k = 0.038 and n = 0.704, R^2 = 0.973, MSE = 0.0011 and (Chi-square) value of sapota slices was 0.14. The average product temperature was 49 ± 1.98°C. The average ambient temperature was 34.27 ± 1.78°C. The ambient air temperature varied from 38.12 to 55.08 °C. The product temperature varied from 36.04 to 47.14°C. Quality parameter of solar drying is TSS 60 (°B); acidity 0.21(%); pH 6.03; reducing sugar 24.62(%); total sugar 37.51(%); carbohydrate 25.62(%); Protein 1.12(%); fat 1.33(%); ash 1.3(%) and colour L value 66.54; a value 8.1; b value 27.12 respectively.

Keyword: Solar drying, page model, quality parameter etc.

Drying means preservation of food, fruits and vegetables for long time with good quality. It is a process of moisture removal due to simultaneous heat and mass transfer. Agricultural products, especially fruits and vegetables require hot air in the temperature range of 45–60˚C for safe drying. When any agricultural product is drying under controlled condition at specific humidity as well as temperature it gives rapid superior quality of dry product. Drying involves the application of heat to vaporize moisture and some means of removing water vapour after its separation from the food products. It is thus a combined and simultaneous heat and mass transfer operation for which energy must be supplied. The removal of moisture prevents the growth and reproduction of microorganisms like bacteria, yeasts and moulds causing decay and minimizes many of the moisture-mediated deteriorative reactions. It observed that reduction in weight and volume, minimizing packing, storage, and transportation costs and enables storability of the product under ambient temperatures. These features are especially important for developing countries.

Drying is one of the oldest methods for preservation of fruits and vegetables, and is an energy intensive operation. The process involves extraction of moisture from the product by heating, and passage of air mass

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around it to carry away the released vapour. Under ambient condition, these processes continue until the vapour pressure of the moisture held in the product equals that held in the atmosphere (Ekechukwu and Norton, 1999). Under ambient conditions, the drying process is slow and in environment of high relative humidity, the equilibrium moisture content is sufficiently low for safe storage.

Solar drying has been identified as a promising alternative to sun drying for drying of fruits and vegetables in developing countries because of its minimal operational cost in terms of fuel cost. Utilization of solar energy for drying is advantageous because it is a free, renewable, abundantly available, environmental-friendly and economically viable for use by rural farmer. It is also more convenient alternative for rural sector and other areas with scarce or irregular electricity supply (Basunia and Abe, 2001). Sun shine in India is over an average 3000-3200 h per year, delivering about 2000 $kWh.m^{-2} yr^{-1}$ of solar drying of agricultural product with use of solar dryer offers faster drying and more hygienic products. The products are free from insect and bird attack (Tunde-Akintunde *et al.* 2005). Solar dryers either use solar energy for the require heat, or as a supplemental source. The air flow can be generated by either natural or forced convection. The heating process can involves the passage of preheated air through the product or by directly exposing the product to solar radiation, or combination of both. The major requirement is the transfer of heat to the moist product by convection and conduction from surrounding air mass at temperature above that of product, or by radiation mainly from the sun, and to a little extent from surround surfaces, or conduction from heated surface in contact with the product. Absorption of heat by the product supplies the energy necessary for the vaporization of water from the product (Ekechukwu and Norton, 1999) .

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 ₹ 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), phenolics viz, 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).

An average sapota tree yields between 250-2500 fruits depending on its age. It has been observed that when there is bumper production of sapota the fruits go a waste for want of suitable preservation facilities. Considering the fast increasing area under sapota cultivation, preservation and processing technology needs to be developed in order to prevent huge post-Harvest losses and regulate price during glut period and thus protecting the interest of the growers. Drying is a classical method of food preservation, which provides longer shelf life, lighter weight for transportation and small space for storage. It is defined as a process of moisture removal due to simultaneous heat and mass transfer. It can be done by solar dryers, cabinet dryer, frees dryer *etc.* There is a strong demand for convenience foods. This study was conducted to investigate convective hot air drying of sapota slices and to determine the quality of dried product powder. Sapota remains a mostly unexplored fruits, although research has been reported on aspects of its post-Harvest treatment. Studies have been reported on the extension of shelf-life of the fruit by chemical treatments. And drying characteristics of sapota slices are available in the literature One way to increase the shelf-life of sapota would to process it in to powder, as is done with various other fruits. Dried sapota slices powder can be stored much longer than fresh fruit. The purpose of a dryer is to supply more heat to the product than that available naturally under ambient conditions, thus increasing sufficiently the vapour pressure of the crop moisture. Therefore, moisture migration from the crop is improved. The dryer also significantly decreases the relative humidity of the drying air, and by doing so, its moisture-carrying capability increases, thus ensuring sufficiently low equilibrium moisture content.

Seema Kumari (2016) studied drying behaviour of sapota *(Manikara Achras)* in solar dryer. Bala *et al.* (2009) used a solar tunnel dryer for drying of mushroom, Tunde-Akintunde *et al.* (2005) studied the influence of open sun, solar and artificially air drying method of drying on bell-pepper, Hassanain (2009) carried out experiment on solar drying of banana fruits.

The present study was undertaken to study the drying characteristics of solar drying of sapota slices. The change in quality parameter, i.e., acidity, pH, TSS, reducing sugar, non- reducing sugar, protein, fat, carbohydrates and ash was also discussed**.**

MATERIALS AND METHODS

Moisture Content Determination

Sapota *(cv.kalipathi)* fruits were procured from the Dapoli market. 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 after removal of peel were cut into two halves. The peel and seed portion separated manually by knife. 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).

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

Where,

W_1 = weight of sample before drying, gram

W_2 = weight of bone dried sample, gram

Drying rate

The drying rate of sapota slices was calculated on dry basis using following formula;

$$R = \frac{W_r}{T \times W_d} \times 100 \qquad \ldots (2)$$

Where,

R = Drying rate (g/min)

W_r = Amount of moisture removed (g.)

T = Time taken (min)

W_d = Total bone dry weight of sample (g.)

Experimental setup

Solar drying

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

Drying Characteristics

Moisture content (% db) versus drying time (min) and drying rate (kg. of water / 100g dry solid/min) with respect to moisture content was determined for tray 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 fitted to the experimental data on moisture ratio versus drying time in minutes of sapota slices with tray drying. The moisture ratio determine the unaccomplished moisture changes, defined as the free from water still to be removed, over the initial total free water (Henderson and Pabis, 1961).

For an investigation of drying characteristics of sapota slices, it is important to model drying behaviour effectively. In this study, the experimental drying data of sapota slices at solar drying were fitted using five models given in Table 1. In this model, (MR) represents the dimensionless moisture ratio. The moisture ratio (MR) and the drying rate of sapota slices during experiments were calculated using the following equation. The moisture ratio of sapota slices was calculated on wet basis using following formula (Chakraverty, 2003);

$$MR = \frac{M - M_e}{M_o - M_e} \quad \ldots (3)$$

Where,

MR = Moisture ratio; M = Moisture content at any time θ, % (db); $M_e = EMC$, % (db); M_0 = Initial moisture content, % (db)

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 ($-kt^n$)	Zhang and Litchfield (1991)
3	Modified Page	MR= Exp – (kt^n)	Overhult *et al.* (1973)
4	Exponentials	R = exp (-kt)	Bakker-Arkema, 1997
5	Thompson	MR = α exp ($-kt^n$) + bt	Sacilik *et al.* 2006
6	Modified Page equation	MR=exp($-(kt^n)$)	Zhang and Litchfield, 1991

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

Where,

MR_{exp} = experimental moisture ratio

MR_{Pre} = predicted moisture.

Non-linear regression analysis was performed to the experimental data by using SAS 6.0. 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.* (2007a) 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.

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.

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

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:

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

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 (8) can be simplified further (Lopez *et al.* 2000; Doymaz, 2004) as:

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

The diffusivities are typically determined by plotting the experimental drying data in the terms of Ln. (MR) vs. drying time (t) in Equation (9), because the plot gives a straight line with the slope as follows.

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

Where,

L = half thickness

Evaluation of Quality parameters for the sapota powder Product

Total soluble solids (^{0}brix)

Total soluble solids dried sapota slices before and after solar 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 experiments were replicated three times.

Titratable acidity

The Titratable acidity of sapota slices before and after solar drying was determined by Ranganna (1997). A known 15g 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 readings were reported.

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

Where,

N = normality of alkali
T = titrate reading
E = equivalent mass of acid, g
W = weight of the sample, g
V = total volume of the sample, g

pH

pH of sapota slices before and after solar 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 sapota slices was determined for three replication.

Reducing sugars

The reducing sugars sapota slices before and after solar 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 =

$$\frac{1000}{\text{Butter reading}} \times \frac{\text{Volume prepared}}{\text{initial volume}} \times \qquad \ldots(11)$$
$$Gv \text{ off chling soln.}$$

Where,

GV = Glucose value.

Total sugars

Total sugars sapota slices before and after solar 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. 12). The experiment was repeated three times to get the replication.

Total sugar =

$$\frac{\text{Factor} \times \text{Dilution}}{\text{Tite reading} \times \text{weight of sample}} \times 100 \qquad \ldots(12)$$

Carbohydrate

The carbohydrate from sapota slices before and after solar 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 cuvette 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,

$$\text{Concentration \%} = \frac{\text{Absorbance of unknown} - \text{Concentration of standard}}{\text{Absorbance of standard}} \quad \ldots(13)$$

Protein

The protein content of sapota slices before and after solar 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 covet of spectrophotometer up to>3/4 of its level. The absorbance was read against standard protein solution at 750 nm. Absorbance is recorded as protein content.

Fat (%)

Fat of sapota slices before and after solar 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 and after solar drying at 40, 50, 60 and 70°C 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 (13).

$$\text{\% Ash (w/w)} = \frac{\text{Weight of sample portion, } g - \text{weight loss on ashing, } g}{\text{Weight of sample portion, } g} \quad \ldots(14)$$

Colour

The sapota slices before and after solar 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 sapota dried 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. 1 shown change in moisture content (db) % with respect to time (min) of sapota dried slices by solar drying. The sapota dried slices from an initial moisture content of 271.33 % (db) to 9.60 % (db). It took around 59 h for drying of sapota slices. It took around 6 days to complete the drying process.

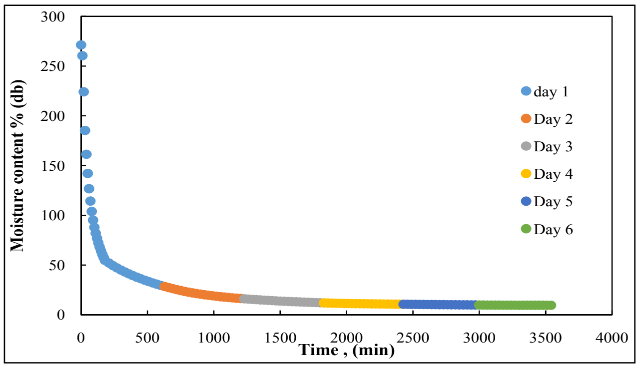

Fig. 1: Moisture content % (db) versus time (min) for solar drying of sapota slices

Fig. 2 shown the drying rate (kg water removed/ 100 g bone dry material/ min) w.r.t. moisture content % (db) of dried sapota slices by solar drying. The drying rate varied from 0.62-0.006 kg water removed / 100 g bone dry materials / min. The drying took place in falling rate period at the initial period drying rate was faster 0.62 kg water removal/ 100g dry solid/ min and it decreases up to 0.006 kg of water removed/ 100g dry solid/min at the end of drying.

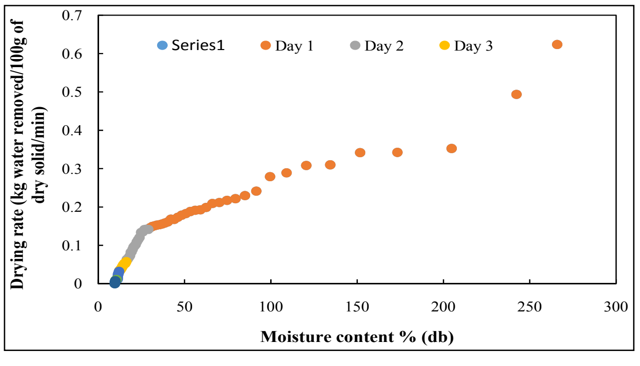

Fig. 2: Drying rate (kg water removed / 100 g dry solid / min) versus moisture content % (db) of sapota slices by solar drying

Fig. 3 shows the variation in moisture ratio with respect to the time consumed for drying during 6 days of solar drying of sapota slices. Moisture ratio decreased from 1.00 to 0.001 as time of drying increased.

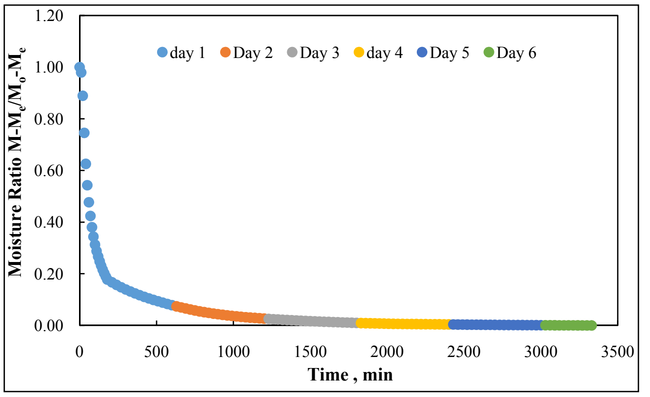

Fig. 3: Variation in the moisture ratio with respect to time (min) drying solar of sapota slices

The change in the moisture ratio with time drying of sapota slices in given in Fig. 3. The similar cure was observed Kunari *et al.* (2016), Suchita *et al.* (2014), Sawant *et al.*, (2013) for sapota slices.

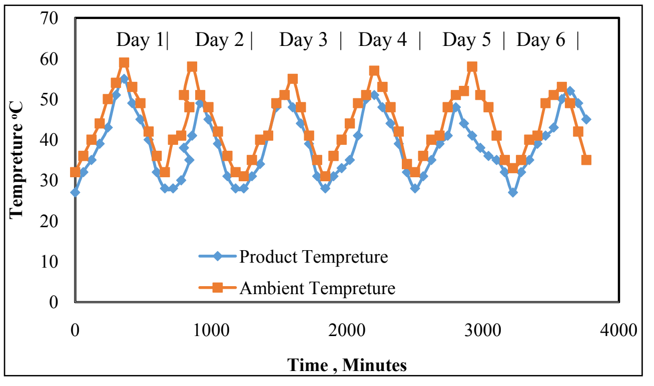

Fig. 4: Variation in Product temperature (°C) and ambient air temperature (°C) versus time (min)

Fig. 4 shown the product temperature and ambient air temperature w.r.t time during 6 days solar drying of sapota slices. The average product temperature was 49 ± 1.98°C. The average ambient temperature was 34.27 ± 1.78°C. The ambient air temperature varied from 38.12 to 55.08 °C. The product temperature varied from 36.04 to 47.14°C.

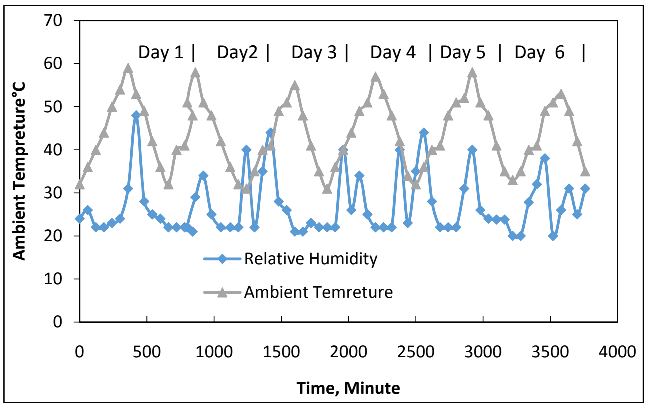

Fig. 5: Variation in ambient temperature and relative humidity with time in solar drying of sapota slices

Fig. 5 shows change in ambient air temperature (°C) and relative humidity (%) with respect to time during the 6 days of solar drying. The average relative humidity (%) for the ambient air inside the drying was 27.42 %, and varied from 22.00 percent to 42.23 percent.

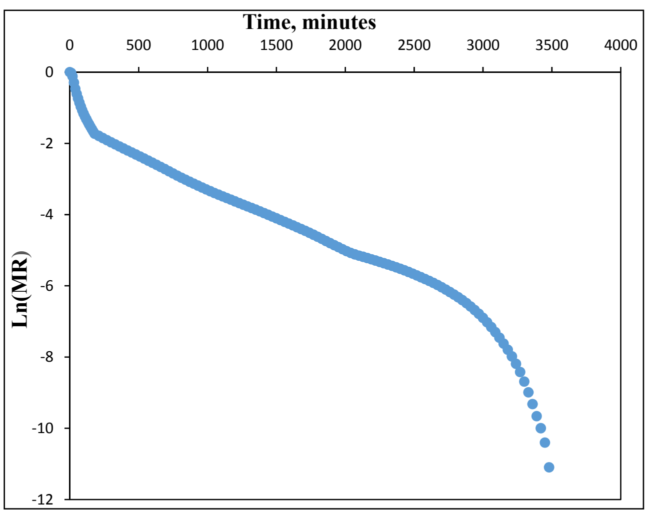

Fig. 6: Ln(MR) versus time, minutes for effective diffusivity for Solar drying of Sapota slices

Fig. 6 is shows the Ln(MR) versus time, minutes for effective diffusivity for solar drying of sapota slices, and R^2 = 0.0.8626. The Effective Diffusivity (D_{eff}) time (t) for sapota drying by solar drying was 2.53154 × 10^{-8} m²/s. The effective diffusivity was in the range of 1.973^{-10} to 8.059^{-11} for fig drying. (Doymaz *et al*. 2011), 3.2^{-9} m²/s to 11.2^{-9} m²/s for red bell pepper (Vega *et al.* 2007), the effective diffusivity was in the range of Mango slices drying 3.89^{-10} to 4.86 10^{-10} (Kabiru *et al.* 2013). The okra fruits in solar drying effective diffusivity was 1.12^{-10} to 1.52^{-11} (Ibrahim Doymaz, 2011).

Table 2 shows the value of drying constants, R^2, and RMSE of different models fitted to the experimental data on solar drying of sapota slices i.e. Newton, Page, Modified Page, Exponential, Thompson, Logarithmic and Modified Page equation-II. Out of these models Page model was well fitted to the experimental data on solar drying of sapota slices. The parameter of Page model are k = 0.038 and n = 0.704, R^2 = 0.973, MSE = 0.0011 and (Chi-square) value of sapota slices was 0.14. The Akpinar (2008) had found Wang and Singh model to fit well to the behaviour of Parsley leaves dried under solar dryer, Babalis *et al*. (2006) found the Two term exponential model well fitted to the solar drying of figs, Sacilik *et al*. (2006) found the Diffusion model well fitted to the solar tunnel drying of organic tomato.

Evaluation of quality parameter for sapota dried product

Moisture (% wb)

Moisture content of sapota slices before solar drying was 75.5(% wb) after drying was 9.60 (% wb). Hande *et al.* (2016), reported that moisture content of kokum rind before drying was 574.14 % (d.b) and decreases up to 11.49 % after dried at solar dryer.

TSS (° BRIX)

The total soluble solid of were sapota slices before drying and after solar drying was 19.45 and 60(°B). Increase in TSS of after drying was significant at 0.05). Kumari *et al.* (2016) reported the sapota powder TSS was in the range of 15.73 to 18.36 °B, Ganjyal *et al.* (2005) reported the sapota powder TSS was in the range of 22 to 28 °B.

Acidity (%)

The acidity of sapota slices before drying was 0.16%, the acidity after drying was 0.21%. There was significant at 0.05) increases in acidity after drying

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

Sl. No.	Model name	Model Parameters	R^2	MSE	(Chi square)
1	Newton	*k*=0.0103	0.9643	0.0015	0.1936
2	Page	*k*=0.0389	0.9733	0.0011	0.1448
		n=0.7046			
3	Modified Page	*k*=0.0099	0.9733	0.0011	0.1448
		n=0.7046			
4	Exponential	*k*=0.0103	0.9643	0.0015	0.1936
5	Thompson	*a*=-1.66939E+02	0.9740	8.65230E+04	1.09884E+07
		b=-1.376113605			
6	Modified Page equation-II	*k*=2.2082	0.9733	0.0011	0.1448
		L=1.75538E+01			
		n=0.7046			

Table 3: Evaluation of Quality Parameters for Solar Drying of Sapota Slices

Sl. No.	Chemical constituents	Before drying	After drying
1	Moisture (% wb)	75.2±1.6	9.60 ± 0.4
2	TSS	19.45± 1.40*	60±2*
3	Acidity (%)	0.16 ±0.14*	0.21±0.005*
4	pH	5.72 ±0.14**	6.03±0.20**
5	Reducing sugar (%)	16.3 ±1.238*	24.62±1.55*
6	Total sugar (%)	48.50 ±1.58**	37.51±0.8**
7	Carbohydrate (%)	19.50 ±3.47*	25.2±0.2*
8	Protein (%)	0.5±0.13*	1.12±0.01*
9	Fat (%)	0.49±0.44*	1.33±0.05*
10	Ash (%)	0.47±0.03*	1.3 ±0.05*
11	Colour L *	71.10±2.43*	66.54±0.03*
	a*	7.14±0.02*	8.1±0.01*
	b*	40.50±0.03*	27.12±0.005*

**= significant at 0.05; **=non-significant at p0.05.*

of sapota slices. Cholera *et al*. (2016) reported sapota acidity was 0.12 (%), Ganjyal *et al.* (2005) reported the in sapota powder acidity was in the range of 0.24 to 0.35 (%), Kumari *et al.* (2016) reported the sapota powder acidity was 0.20 (%).

pH

The pH of sapota slices was 5.72 before solar drying. The pH of sapota slices after solar drying was 6.03. There was significant at 0.05) increases after drying.

Reducing sugar (%)

The reducing sugar of sapota slices before and after solar drying was from 16.3 and 24.62 %. This increase in reducing sugar might be attributed due to attributed due to concentration of fruits flavour during drying. This increase in reducing sugar significant at 0.05).

Total sugar (%)

The Total sugar of sapota slices before and after solar drying was 48.50% and after drying was 37.5%. The decrease in total sugar might attribute due to concentration and loss of moisture in the product. The decrease in total sugar was significant at 0.05). The increase of total sugar in sapota slices after drying in solar drying was in agreement with the reported results in literature with 19.22 to 45.96 % by the Abrol *et al.* (2014).

Table 4: ANOVA table

Sl. No.	parameter	S.E (5%)	C.D (5%)
1	TSS (°B)	0.58	1.88
2	Acidity (%)	0.01	0.05
3	pH	0.04	0.12
4	Reducing sugar (%)	0.43	1.42
5	Total sugar (%)	0.54	1.75
6	Carbohydrate (%)	0.06	0.19
7	Protein (%)	0.03	0.01
8	Fat (%)	0.03	0.09
9	Ash (%)	0.49	1.61
10	Colour L *	0.05	0.17
	a*	0.09	0.28
	b*	0.22	0.72

Carbohydrate (%)

Carbohydrate of sapota slices before to after solar drying was 19.50 and 25.2. The carbohydrate of sapota slices after drying increase non-significantly at (p0.05). Kumari *et al.* (2016) reported the sapota powder carbohydrate content was 25 %.

Protein (%)

Protein of sapota slices range of before to after drying was 0.5 and 1.12. The protein content was increases at significant at (0.05). Kumari *et al.* (2016) reported the sapota powder protein is 0.92 %, Guruswami *et al.* (2002) reported protein in solar and open dried sapota was 6.5 %.

Fat (%)

Fat of the sapota slices is 0.49 % before drying and increases up to 1.33 %, after solar drying. The fat content in sopota slices after drying increase in significant at (p0.05). Kumari *et al.* (2016) reported the fat content sapota powder was 1.3 %.

Ash (%)

Ash content of sapota slices before and after solar drying was 0.47 % and 1.3 %. The change in ash content of sapota slices after drying was significant at (p0.05). Kumari *et al.* (2016) reported the ash content sapota powder was 84.6 %.

Colour

Colour of sapota slices of L value was before drying and after drying were 71.1 up to 66.54. The L value decreases and a value of sapota slices before drying was 7.14 and increased 8.1 after drying. The b value of sapota slices before and after drying was 40.50 and reached up to 27.12. The colour of sapota slices after drying L, a and b is at significant at0.05). Ali *et al.* (2016) reported colour L, a and b in Guava drying 49.70, 11.70, 31.96 respectively. This variation in colour is due to pigment degradation because of long drying duration.

CONCLUSION

1. In solar drying the sapota slices was dried from initial moisture content of 271.33 % (db) to 9.60 % (db). It took around 59 h for drying of sapota slices. It took around 6 days to complete the drying process. The drying rate varied from 0.62 - 0.006 g water removed / 100 g dry solid / min. The drying took place in falling rate period at the initial period drying rate was faster 0.62 g water removal/ 100g dry solid/ min and it decreases up to 0.006 g of water removed/ 100g dry solid/min at the end of drying.
2. Page model was fitted well in solar drying of sapota slices. Page model value parameter k=0.038 and n=0.704, R^2=0.973, MSE=0.001140263 and Chi square value was 0.144 for sapota slices.
3. The quality parameter of sapota slices in solar drying i.e. acidity, pH, reducing sugar, carbohydrate, protein, fat and ash was increased

and total sugar was decreased. The colour value i.e. L and b was decreased during solar drying and a value was increased during solar drying. Acidity was increased from 0.16 to 0.21 %; pH was increased from 5.72 to 6.03; reducing sugar was increases 16.3 to 24.62 %; carbohydrates was increase from19.50 to 25.2 %; protein increase from 0.5 to 1.12 %; fat increase from 0.49 to 1.33 %, ash increases from 1.3 to 83.1 %.

4. The total sugar of sapota slices before and after drying was decrease from 48.50 to 37.51 %, colour of dried sapota slices decreases from is L 71.10 to 66.54, a value increases from 7.14 to 8.1 and b value decreases from 40.50 to 27.12.

Table 5: Nomenclature

MR	Moisture Ratio
a, b, c, g, k, n and l	Constant
t	Time, min
M	Moisture Content at time t, % db
M_e	Equilibrium Moisture Content, % db
M_0	Initial Moisture Content, % db
r	Co-relation Coefficient
$RMSE$	Root Mean Square Error
MR_{exp}	Experimental Moisture Ratio
MR_{pre}	Predicted Moisture Ratio
D_{eff}	Effective diffusivities, m2/s
R^2	Radius, m

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