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Research Paper

Convective Hot Air Drying of *Aloe vera* Slices and its Quality Evaluation

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ABSTRACT

In the present study, the convective hot air drying of *Aloe vera* slices was performed at 45, 55, and 65°C. The drying characteristic i.e. moisture content versus time, Drying rate versus moisture content, and moisture ratio versus time, was discussed. Three mathematical models were fitted to the experimental data on moisture ratio versus time i.e. Newton, Page and Henderson pabis models were fitted to the experiment data. The page model was fitted well. The dried slices were evaluated for their various nutritional and functional quality parameters i.e. moisture content, protein, fat, ash, fiber, carbohydrate bulk density, water absorption capacity, and wettability. The protein decreased from 7.10 ± 0.03 to 5.57 ± 0.03, fatwas decreased from 2.02 ± 0.12 to 1.97 ± 0.10, ash increased from 16.33±0.29 to 17.33±0.29, fiber decreases was from 14.98 ± 1.38 to 14.92 ± 2.65, carbohydrates was increases from 54.68 ± 1.71 to 54.97 ± 2.75, bulk density decreases from 0.48 ± 0.01 to 0.45 ± 0.01, water absorption capacity increases from 1.34 ± 0.06 to 2.35 ± 0.50, and wettability increases from 35.00 ± 1.00 to 36.67 ± 0.58 respectively when the temperature of drying increases form 45 to 65°C. The functional properties can be helpful for the development of herbal cookies etc.

Keywords: *Aloe vera*, convective hot air drying, physico-chemical properties, functional properties

Aloe barbadensis miller, commonly referred as *Aloe vera*, is one of more than 400 species of aloe belonging to the family Liliaceae that has originated in South Africa. But have been indigenous to dry subtropical and tropical climates, including Southern USA (Reynolds and Dweek, 1999). *Aloe vera* is well recognized as a source of valuable material in functional foods, cosmetics, and herbal medicines (Kawai and others, 1993; Eshun and He, 2004; Rodriguez *et al*. 2010). Physical and biochemical properties of *Aloe vera* gel have been well characterized (Femenia *et al.* 2013; Femenia *et al.* 1999) and extensively investigated (Ni *et al.* 2004; Rodriguez-Gonzalez *et al.* 2011; Sharrif and Sandeep, 2001). The plant posses' bioactive polysaccharides such as acemannan, glucomannan, pectin, and aloeride responsible for diverse biological activities such as immunomodulatory, anti-inflammatory, anti-diabetic, anti-cancerous, etc. (Ahlawat and Khatkar, 2011; Ramachandra and Rao, 2008). *Aloe vera* products were used in the manufacture of medical products such as burn treatments, ointments, and medicated creams and lotions of topical applications to fight various skin disorders (Eshun and He, 2004). Furthermore, these aloe species are listed in the pharmacopeia of many countries in the form of plain aloe, extract, and

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powder (Park and Jo, 2006). The allowable routes of administration are oral or topical; dried leaf latexes were for oral uses and as laxative or vermifuge, whereas leaf gels were for topical and used to treat minor burns and cuts and sunburns (Willard, 1991; Leung and Foster 1996; Williamson, 2003). Leaf gels were also used to assist in wound healing (Boon and Smith, 2004).

The numerous beneficial effects of *Aloe vera* are primarily due to its anthraquinones, polysaccharides, and low molecular weight substances (Choi and Chung, 2009; Cha *et al*. 2007). Global market data reveals that the opportunities are expanding in the herbal sector, with a market growth rate of 15% per annum in India and 7% per annum in the world. The total production of aloe in India is estimated to be about 1, 00,000 tons (Anonymous, 2006). The main feature of the *Aloe vera* plant is its high water content, ranging from different potentially active compounds, including water and fat-soluble vitamins, minerals, enzymes, simple/complex polysaccharides, phenolic compounds, and organic acids. In compositional studies on the structural components of the *Aloe vera* plant leaf portion, the rind was found to be 20-30% and the pulp 70-80% of the whole leaf weight. On a dry-wet basis, the percentage of the rind and pulp represented as lipids (2.7% and 4.2%) and as protein (6.3% and 7.3%) only accounts for a minor fraction (Femenia *et al.* 1991). Fig. 1(a) and (b) show the *Aloe vera* plant and *Aloe vera* slices.

Drying is a process to remove or reduce moisture content in a material by supplying heat energy for evaporation in various manners. Convection hot air drying method is considered the most popular drying method applied to plant material (Lewicki, 2006). Owing to the favorable cost efficiency ratio, it allows achieving of large quantities of dried product (Figiel, 2010). Drying prevents (or inhibits) the development of microorganisms, improves food preservation, and reduces the weight and bulk of food for cheaper transport and storage. As well, the reduction in moisture content below a certain level can reduce the microbial damage of dried food materials and be accompanied by proper treatment (Jangam *et al*. 2010). In drying, applied external heat evaporates surface moisture, while internal moisture may be forced to the surface and then evaporated. Moisture can be evaporated internally and then transported to the surface; the transfer of heat depends on the air temperature, air humidity, air flow rate, pressure, surface area, the physical nature of the material as well as its composition and the process by which the heat is transferred to the material be it by conduction, convection or radiation. The convection hot air dryer operates at atmospheric pressure under steady drying conditions using hot air as a drying medium and convection as a mode of heat transfer (Mujumdar and Law, 2010). Besides, convection drying consists of passing heated air through layers of products, such as apples, plums, herbs and vegetables (Raghvan and Orsat, 2007).

Ash content represents the total mineral content. It is a part of proximate analysis for nutritional evaluation. Ash is the first step in preparing a sample

(a) *Aloe vera* plant

(b) *Aloe vera* slices

Fig. 1: (a) *Aloe vera* plant and **(b)** *Aloe vera* slices

for specific elemental analysis. Because certain samples are high in particular minerals, ash content becomes important (Nielsen, 2009). Water absorption capacity represents the ability of a product to associate with water under conditions where water is limited (Singh, 2001). Water absorption capacity is important in the development of ready-to-eat foods, and a high water absorption capacity may assure product cohesiveness (Ogunlakin *et al*. 2012). Color is an important quality factor directly related to the acceptability of food products and is an important physical property to report. Bulk density is a measure of the heaviness of flour and is generally affected by the particle size and the density of the flour (Gull *et al*. 2002). Okezie and Kosikowski (1981) reported that wettability is the time required by flour to reach its wetness. Wettability is important in reconstitution in water; it is related to the presence of soluble molecules, and lower wettability indicates better reconstitution properties (Colona *et al*. 1989).

MATERIALS AND METHODS

Raw material

Aloe vera plant leaves were procured from the farmers' field at Sangli. The turbid, affected part was trimmed off. The leaves were washed to remove dirt, dust, and surface moisture and were removed was used for the present study.

Determination of Moisture content

The moisture content of the *Aloe vera* slices of 1 cm thick was determined by AOAC (2010). 10-15 g of slice samples were taken into each of the four different moisture boxes. The initial weight of the moisture box was recorded. The samples were exposed to 105˚C ± 1˚C for 24 hr in a hot air oven (Make M/s: Aditi Associate, Mumbai. Model: ALO-136). The final weight was recorded. The moisture content of the slices was determined by equation (1);

$$\text{Moisture content (\% db)} = \frac{W_2 - W_1}{W_3 - W_1} \times 100 \qquad \ldots(1)$$

Where,

W_1 = weight of moisture box, *g*

W_2 = Weight of moisture box + sample *g*

W_3 = Weight of moisture box + oven dried sample, *g*

Experimental setup

The tray drying of *Aloe vera* leaves was performed in the Department of Post Harvest Engineering, Post Graduate Institute of Post Harvest Management, Roha. *Aloe vera* leaves were washed to remove dirt and dust using tap water, and the surface moisture was removed. The *Aloe vera* leaves were sliced into small pieces of 1 cm thickness. The slices were placed in the Stainless Steeltray in a single layer. The size of the tray was 81 × 41 × 3.4 cm. The drying was carried out in a single layer in a tray dryer (M/s: Aditi Associate Mumbai; Model: ATD-124) having a capacity 5 kW. There were 9 no. of trays. The temperature of the drying was kept 45˚C, 55˚C and 65˚C ± 1˚C. The *Aloe vera* drying was carried out in a thin layer drying. The air velocity inside the dryer was 2 m/s. The weight loss w.r.t. time was recorded from the trays at different locations in the tray dryer. The moisture content w.r.t. time was calculated from the drying data.

Drying characteristics

Moisture content (%db) versus drying time (min) and drying rate (g of water removed /100 g of bone dry material/min) with respect to the moisture content was determined for tray drying of *Aloe vera* slices moisture ratio versus time was also determined.

1. Drying rate

The drying rate of *Aloe vera* slices was calculated on a dry basis using the following formula (Chakraverty, 1994).

$$= \frac{}{T \times W} \times 100 \qquad \ldots(2)$$

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)

2. Moisture ratio

Moisture ratio versus drying time (min) was also determined from experimental data. The various mathematical models listed in Table 1 i.e. Newton, Page Henderson and Pabis were fitted to the experimental data on moisture ratio versus drying time in min of *Aloe vera* slices dried with tray drying. The moisture ratio determines the unaccomplished moisture change, defined as the ratio of the free water still to be removed at time t over the initial total free water (Henderson and Pabis, 1961).

The moisture ratio is usually expressed as;

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

Where,

MR is the dimensionless moisture ratio,

M is the moisture content at time t,

And M_o and M_e are the initial and equilibrium moisture contents, respectively, on dry basis.

3. Root Mean Squar Error

The root mean squar error was determined as per the following equation (4);

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

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).

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 the lower the chi-square (χ^2) and RMSE values, the better is the goodness of fit (Ozdemir and Devers, 1999; Ertekin and Yaldiz, 2004; Wang *et al.* 2007). According to Wang *et al*. (2007) 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 observations, and z is the number of constants. In this study, the non-linear or linear regression analysis was performed with statistical software SAS 6.0.

Effective moisture diffusivity and activation Energy

The *Aloe vera* slices were assumed to resemble a slab of thickness 10 mm. The solution of Fick's second law in slab geometry, with the assumption that moisture migration is caused by diffusion, negligible shrinkage, constant diffusion coefficient, and temperature, was given by Crank (1975) as follows:

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

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

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

The diffusivities are typically determined by plotting the experimental drying data in terms of $ln(MR)$ vs. drying time (t) in eqn (7), because the plot gives a straight line with the slope as follows:

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

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 (Eq. 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 Eq. (8). The 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) represented diffusivity as temperature dependent with Arrhenius expression as;

$$D_{eff} = D_o . \exp.\left(\frac{-E_a}{R(T + 273.15)}\right) \quad \ldots(9)$$

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, kJ/ (mol·K)

Rearranging Equation (9) gives Equation (10):

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

Table 1: Mathematical models tested with the moisture ratio of *Aloe vera* powder

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

The energy of activation can thus be calculated from Eq. (9), which gives a relationship between temperature and effective moisture diffusivity. The plot of Ln (D_{eff}) versus 1/(T+273.15) gives a straight line (slope of K_L= Ea/R). Linear regression analysis was used to fit the equation to the experimental data to obtain the coefficient of determination (R^2).

Evaluation of Quality parameters for dried product

1. Moisture content

The moisture content of the *Aloe vera* slices, which were of 1 cm thick and dried at 45, 55, and 65°C was determined by AOAC (2010). 10-15 g of slice samples were taken in to each of the four different moisture boxes.

2. Protein

Crude protein of the *Aloe vera* powder was determined using the Kjedahl method according to AOAC (1990). 1g of the *Aloe vera* powder, which was of dried slices at 45, 55 and 65°C was taken into the digestion flask. Kjedahl catalyst (Selenium tablets) was added to the sample. Twenty milliliters of concentrated sulphuric acid was added to the sample and fixed to the digester flask for eight hours until a clear solution was obtained. The cooled digestermass was transferred into a one hundred milliliters volumetric flask and made up to the mark with distilled water. The distillation apparatus was set and rinsed for ten minutes after boiling. Twenty milliliter of 4% boric acid was pipetted into conical flask. Five drops of methyl red was added to the flask as indicator and the sample was diluted with seventy five milliliter distilled water. Ten milliliter of the digested sample was made alkaline with twenty miles of NaOH (20%) and distilled. The steam exit of the distillatory was closed and the change of color of boric acid solution to green was timed. The mixture was distilled for fifteen minutes. The filtrate was then titrated against 0.1 N HCL. % Nitrogen of the sample was calculated from equation (11) and % protein was calculated from equation (12);

$$\%N = \frac{(Sample\ titre - Blank\ titre) \times N\ HCL \times 1.4 \times 100}{Weight\ of\ sample} \times 100 \quad \ldots(11)$$

% protein = % nitrogen × conversion factor (6.25) …(12)

3. Fat

Fat content of *Aloe vera* sliced powder dried at 45, 55, and 65°C was determined by the soxhlet fat extraction system (AOAC, 2010) by Soxhlet apparatus (Make: Elico, Hyderabad). In this method, the initial weight of the empty flask was weighted. 2 g *Aloe vera* powder was wrapped in filter paper. The sample with filter paper was kept in a siphoning tube, and the condenser was fixed above it and siphoned for 9-12 times with the petroleum ether in a soxhlet apparatus. After removing the assembly, evaporation of petroleum ether was allowed by heating the round bottom flask. Residue remained at the bottom of the flask and was reweighted with the flask. The quantity of residue was determined as fat content of malt and flour. The experiment was replicated for 3 times. The average value of fat content is reported. The fat content was calculated by using following equation (13);

$$\% \text{ Fat content} = \frac{\text{Final wt.} - \text{Initial wt.}}{\text{Wt. of sample}} \times 100 \quad \ldots (13)$$

4. Ash

Ash content of *Aloe vera* slice powder dried at 45, 55, and 65°C was determined by using a muffle furnace (Make M/s:Bio-TECHNICS, India; Model: BTI-3C). 5 g of the powder sample of *aloe vera* was taken in a crucible. Weight of crucible and powder was recorded; the crucible with sample was kept in a muffle furnace at 650°C for 4-5 h till constant weight was achieved. It was observed for their constant readings. The crucible was cooled in desiccators, and the final weight of the ash and crucible was recorded. The experiment was replicated 3 times. The average value of ash content is reported. The ash content was calculated by using the following equation (14);

$$\text{Ash} = \frac{W_2 - W}{W_1 - W} \times 100 \quad \ldots (14)$$

Where,

W = weight of crucible, *g*;

W_1 = weight of crucible and *Aloe vera* powder, *g*; and

W_2 = weight of crucible with ash, *g*

5. Crude fiber

The fiber content *Aloe vera*slice powder, which was dried at 45, 55 and 65°C was determined by the fat-free sample available in filter paper from the fat extraction method (Ranganna, 1986). The filter paper and fat-free residue were kept in the oven at 105°C for 5-6 hours. Around 2 g sample from oven was taken into 600 ml beaker and boiled; 200 ml of 1.25 % H_2SO_4 was added to it. The beaker containing the solution was placed on hot plate for 30 min. After heating residue from the beaker was filtered through filter paper and rinsed beaker with 50 to 75 ml boiling water for three times. The filtered residue from filter paper was dried by convective hot air drying for 2-3 h at 130°C. The dried residue from the convective hot air dryer was transferred to 600 ml beaker and boiled, 200 ml 1.25 % NaOH was added to it and boiled for 30 more minutes on a hot plate. After heating, residue from the beaker was filtered through filter paper and rinsed the beaker with 50 to 75 ml boiling water three times. The filtered residue from filter paper was dried by convective hot air drying at 130°C for 2h. The dried residue was weighed after cooling, and weight was noted. The weighed residue was transferred to a crucible in a hot air oven and ignited for 30 minutes at 600°C and reweighed after being cooled in desiccators for 30 min, and weight was recorded. The experiment was replicated 3 times. The average value of crude fiber content is reported. The crude fiber content was calculated by using the following equation (15);

$$\% \, Fiber = \frac{Weight\ of\ residue\ with\ crucible - Weight\ of\ ash\ with\ crucible}{Weight\ of\ sample} \times 100 \quad \ldots (15)$$

6. Carbohydrates

Carbohydrate content of the *Aloe vera* slice powder samples, which were dried at 45, 55 and 65°C was determined by subtracting the total sum of protein,

fiber, ash and fat from the total dry matter (Vengaiah *et al*. 2013). The carbohydrate was calculated by using the following equation (16);

% Carbohydrate = 100 − (% protein + % fat + % fiber + % ash + % moisture content) … (16)

7. Bulk density

The bulk density of *Aloe vera* slice powder which was dried at 45, 55 and 65˚C was determined according to the method described by (Vengaiah *et al.* 2013). A graduated measuring cylinder of 5 ml was weighed, and *Aloe vera* powder sample was filled into it by constant tapping until there was no further change in volume. The cylinder with the flour sample was weighed and the difference in weight was determined. The experiment was replicated for 3 times the average value of bulk density is reported. The bulk density was calculated by using equation (17);

$$\text{Bulk density} = \frac{W2 - W1}{Volume\ of\ sample} \times 100 \quad \ldots(17)$$

8. Water absorption capacity

The water absorption capacity of *Aloe vera* slice powder, which was dried at 45, 55 and 65˚C was determined by the method of Chandra and Samsher, 2013. 1g of powder sample was mixed with 10 ml distilled water in centrifuge tube and allowed to stand at ambient temperature (30˚C) for 1h, the mixture was centrifuged by using centrifuge (Make: M/s Remi Electrotecnik Limited, Thane, India; Model: R-8C BL) for 30 min at 2000 rpm. The sediments were weighed after the complete removal of the supernatant. The experiment was replicated 3 times. The average value of water absorption capacity is reported. The water absorption capacity was calculated by using equation (18);

$$WAC = \frac{(W_2 - W_1)}{W_0} \times 100 \quad \ldots(18)$$

Where,

W_0 = weight of the sample, *g*; W_1= Weight of centrifuge tube plus sample, *g* and W_2 = weight of centrifuge tube plus the sediments.

9. Wettability

Wettability of the *Aloe vera* slices powder dried at 45, 55 and 65˚C was determined with an (Atomizer, 1978). 100 ml of distilled water (at 21˚C) was poured into a beaker. A flour and malt sample (10g) was placed around the pestle (inside the funnel so that it blocked the lower opening). The pestle was lifted and the stopwatch was started at the same time. Finally, the time was recorded when the flour and malt became completely wetted (visually assessed as the time when all the flour and malt particles penetrated the surface of the water.

10. Colour

Colour of *Aloe vera* slice powder which was dried at 45, 55 and 65˚C was measured by using Konica Minolta color Reader. (Make: Minolta Camera Co. Ltd. Japan Model: (R-10). The color of the samples was measured in a dark room. The powder samples of *aloe vera* was placed on a white surface and placing the color reader was placed on the flour sample in a Petri dish, and the color was measured in L, a, b were reported. Where L value indicates a degree of lightness or darkness, 'a' value indicates redness or greenness and 'b' value indicates the yellowness or blueness.

Statistical Analysis

The data for various physico-chemical properties of *Aloe vera* powder was analyzed by ANOVA and the statically significance was tested using Microsoft Excel 2007 software. The test ofsignifance was performed at $p \leq 0.01$.

RESULTS AND DISCUSSION

Drying Characteristics

Fig. 1 shows Average moisture content (% db) w.r.t. time (min) of *Aloe vera* slices dried by convective hot air drying at 45˚C, 55˚C and 65˚C. The *Aloe vera* slice was dried from an average initial moisture content of 4684.68 to 7.388 (%db); 1372.75to 8.60 (%db) and 1236.89 to 9.319 (%db) and took around 34 h, 19h and 12h at 45˚C, 55˚C and 65˚C respectively.

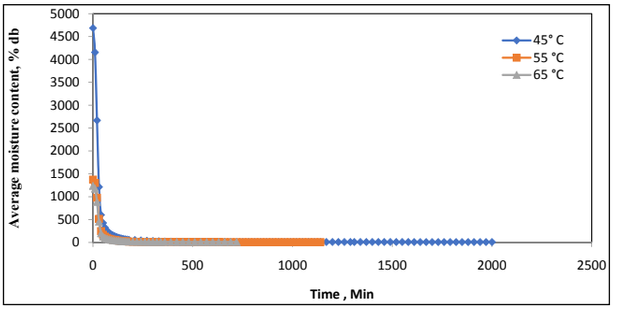

Fig. 1: Average moisture content (%db) Versus Time (Min) for *Aloe vera* slices dried by convective hot air drying

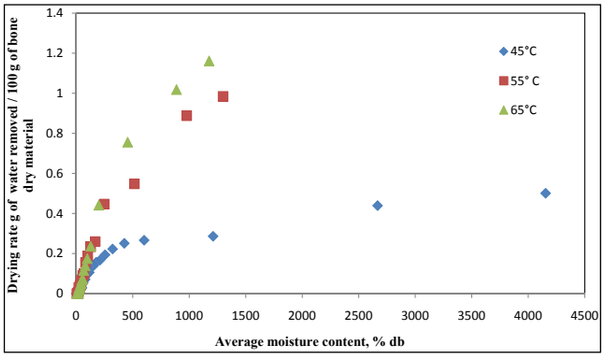

Fig. 2: Drying rate (g of water removed /100 of bone dry material/min) versus average moisture content (%db) of *Aloe vera* slices dried by convective hot air drying at different temperatures

Fig. 2 shows the drying rate (g water removed/100 g of bone dry solid/ min) w.r.t. moisture content (%db) of *Aloe vera* slices dried at 45˚C, 55˚C, and 65˚C, respectively. The drying rate was 0.5011 to 1.67 × 10^{-6} g of water removed /100g of bone dry solid /min at 45˚C, from 0.9843 to 1.12 × 10^{-5} g of water removed /100g of bone dry solid /min at 55˚C and from 1.1613 to 1.66 × 10^{-5} g of water removed /100g of bone dry solid /min at 65˚C which indicates that as temperature increases from 45˚C to 65˚C the drying rate increases. Similar kind of results has been observed for *Aloe vera* in the literature Kaleta *et al.* (2010); Fang *et al.* (2009).

Fig. 3 shows the moisture ratio w. r. t. drying time of *Aloe vera* slices dried at 45, 55 and 65˚C. Table 2 shows the model parameter of Newton's, Page Henderson and Pabis model fitted to the experimental data on moisture ratio versus time. The model parameters, correlation coefficients, RMSE, and the chi-square value, are also given. It is clear from the Table 2 that the page model is well fitted $r^2 \geq 0.991$; RMSE ≤ 0.0004 and $\chi^2 \leq 0.022$ among the other models. The model parameter 'k' increases 0.0024 to 0.009, and n increases from 1.822 to 2.231. There is no specific trend was observed for the 'k' value. The 'n' value increase with increase in temperature.

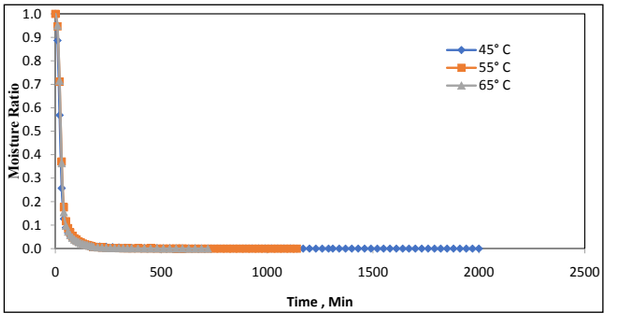

Fig. 3: Moisture ratio Versus Time (Min) of *Aloe vera* drying by convective drying at different temperature

Calculation of effective diffusivity

The temperature dependence of the diffusivity coefficient was described by an Arrhenius-type relationship. The effective moisture diffusivity was calculated by equation (7), using slopes derived from the linear regression of Ln (MR) against drying time (t) data. The plot of Ln (MR) vs. time gives a straight line with the slope (*k*).

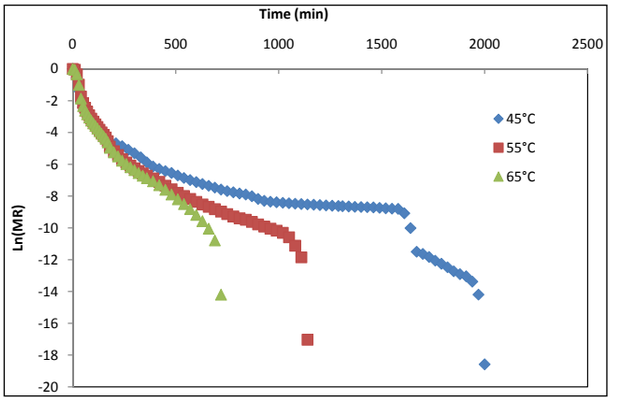

Fig. 4: *Ln*(*MR*) Versus Time in minute for effective moisture diffusivity for convective dried *Aloe vera* powder

Fig. (4), shows Ln (MR) versus time for convective hot air drying of *Aloe vera* slices dried at 45˚C, 55˚C and 65˚C. From the slope, the the effective diffusivity was calculated by using equation (8). Table 3 shows the diffusivity of *Aloe vera* slices at 45˚C, 55˚C, and 65˚C, respectively. The effective diffusivity at 45˚C was 5.0712×10^{-8} m²/s, at 55˚C. It was 9.2296×10^{-8} m²/s and 65˚C. It was 1.4199×10^{-7} m²/s. As the temperature of drying of *Aloe vera* increases the effective diffusivity increases. Based on effective diffusivity at 45˚C, 55˚C and 65˚C.

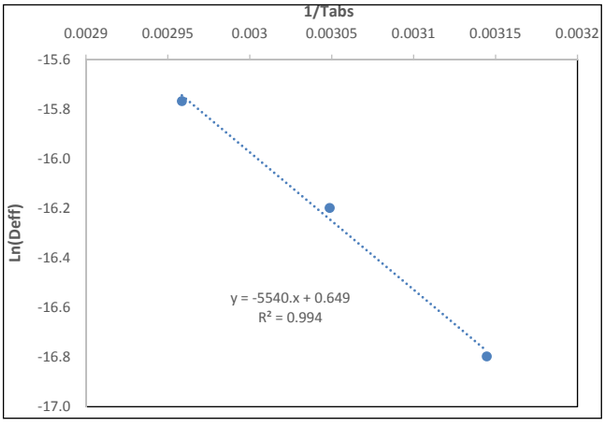

Fig. 5: *Ln*(D_{eff}) versus 1/Tabs of *Aloe vera* slices dried by convective hot air drying

Fig. 5 shows *ln* (D_{eff}) verses $1/_{Tabs}$ of the *Aloe vera* slices. It gives a straight-line equation with slope K_L. From the slope by using equation (10) the activation energy was calculated for the *Aloe vera* slices. The activation energy for *Aloe vera* slices were 0.6664 kJ/mole.

Physico-chemical and functional properties of dried *Aloe vera*

1. Moisture

Table 4 (a) shows the moisture content for *Aloe vera* powder. Moisture content varied for *Aloe vera* powder ranged was 4.88 ± 0.02, 5.55 ± 0.05 and 5.23 ± 0.06 at 45˚C, 55˚C and 65˚C respectively. Highest moisture content is observed at 55˚C drying temperature *Aloe vera* powder. The moisture was significant at p≤0.01. Haque *et al.* (2014) noticed that 6.75 percent moisture content in *Aloe vera* powder. A similar result was observed by Olua *et al.* (2015) reported that the moisture content of the cashew apple powder (6.73) percent was lower than the 7.05 percent reported by Ogunhobi and Ogunwolu (2010).

2. Protein

Table 4 (b) shows the (%) protein content for *Aloe vera* powder. Protein content varied for *Aloe vera*

Table 2: Model parameters, R^2, RMSE and Chi square values of *Aloe vera* powder dried by Convective hot air drying at 45ºC, 55ºC and 65ºC

Newton (Lewis)						
Sl. No.	**Temperature**	***K***	***r²***		***RMSE***	χ^2
1	45°C	0.03749	0.9683		0.0008	0.0700
2	55°C	0.03150	0.9593		0.0019	0.0590
3	65°C	0.0323	0.9532		0.0031	0.1214
Page						
Sl. No.	**Temperature**	***K***	***n***	***r²***	***RMSE***	χ^2
1	45°C	0.0024	1.8228	0.9922	0.0002	0.0171
2	55°C	0.0009	2.0146	0.9913	0.0004	0.0226
3	65°C	0.0004	2.2317	0.9928	0.0004	0.0184
Henderson and Pabis						
Sl. No.	**Temperature**	***a***	***K***	***r²***	***RMSE***	χ^2
1	45°C	1.0937	0.0404	0.9735	0.0007	0.0584
2	55°C	1.1246	0.3482	0.9678	0.0016	0.0836
3	65°C	1.1313	0.0358	0.9626	0.0025	0.0969

Table 3: Effective diffusivity of *Aloe vera* slices dried at varied temperature and Activation Energy

Sl. No.	Temperature ˚C	Effective Diffusivity (m^2/s)	Ea (Activation Energy) $kJ/_{mole}$
1	45˚C	5.0712×10^{-8}	
2	55˚C	9.2296×10^{-8}	0.6664 $kJ/_{mole}$
3	65˚C	1.4199×10^{-7}	

Table 4: Physico-chemical and functional properties of *Aloe vera* Powder

Treatment	Temperature	(a) Moisture	(b) Protein	(c) Fat	(d) Ash	(e) Fiber	(f) Carbohydrate	(g) Bulk density	(h) Water absorption capacity	(i) Wettability	(j) Colour		
											L	a	b
T_1	45˚C	4.88 ± 0.02	7.10 ± 0.03	2.02 ± 0.12	16.33 ± 0.29	14.98 ± 1.38	54.68 ± 1.71	0.48 ± 0.01	1.34 ± 0.06	35.00 ± 1.00	67.08 ± 0.38	2.52 ± 0.02	28.58 ± 0.47
T_2	55˚C	5.55 ± 0.05	6.75 ± 0.03	2.03 ± 0.05	17 ± 0.87	15.8 ± 0.71	52.98 ± 1.82	0.49 ± 0.01	2.22 ± 0.27	31.67 ± 0.58	66.89 ± 0.27	4.04 ± 0.03	30.53 ± 0.32
T_3	65˚C	5.23 ± 0.06	5.57 ± 0.03	1.97 ± 0.10	17.33 ± 0.29	14.92 ± 2.65	54.97 ± 2.75	0.45 ± 0.01	2.35 ± 0.50	36.67 ± 0.58	55.29 ± 0.95	2.11 ± 0.17	27.27 ± 0.27
SEm±	—	0.02	0.01	0.05	0.32	1.02	1.24	0.0	0.19	0.43	0.35	0.06	0.21
CD $_{at\ 1\%}$	—	0.13	0.08	0.28	1.67	5.37	6.49	0.02	1.00	2.26	1.85	0.30	1.10

powder ranged was 7.10 ± 0.03%, 6.75 ± 0.03%, and 5.57±0.03% respectively. Highest protein content is observed in 45˚C of *Aloe vera* powder. The protein content decreases with an increase in temperature from 45˚C to 65˚C. The decrease in protein content w.r.t. increase in temperature was significant at p≤0.01. Similar results was observed by Ahmed *et al.* (2013), who reported that the protein content of *Aloe vera* powder was 6.86±0.06 percent. Gulia *et al.* (2010) reported that protein content in the *Aloe vera* powder sample ranged from 4.64 to 4.65 percent after hot air oven drying from 50˚C to 80˚C respectively. The results are in similar line with the reported value of the protein 4.8 percent (Gautam and Awasthi, 2007).

3. Fat

Table 4 (c) shows the (%) fat content of *Aloe vera* powder. Fat content varied for *Aloe vera powder* from 2.03±0.05(%) to 1.97±0.10 (%) at 45˚C, 55˚C and 65˚C respectively. The highest fat content is observed at 55˚C of *Aloe vera* powder. The decrease in fat was significant at p≤0.01. Similar results were observed by Gulia *et al.* (2010), who reported that the fat content of *Aloe vera* powder ranged was 2.05±0.05, 2.05±0.08, 2.1±0.10 and 2.12±0.11 percent at 50, 60, 70 and 80˚C respectively. Haque *et al.* (2014) noticed that 1.83 percent fat content in *Aloe vera* powder. Ahmed *et al.* (2013) noticed that 2.91±0.09 percent fat content in *Aloe vera* powder.

4. Ash

Table 4 (d) shows the ash content for *Aloe vera* powder. Ash content varied for *Aloe vera* powder ranged was 16.33±0.29 (%) to 17.33±0.29 (%) at 45˚C, 55˚C and 65˚C respectively. Highest ash content observed at 65˚C of *Aloe vera* powder. The ash content increases with increase in temperature 45˚C to 65˚C. The increase in ash was significant at p≤0.01. Haque *et al.* (2014) reported that 19.50 percent ash content in *Aloe vera* powder. Gulia *et al.* (2010) reported that ash content in the dried leaf powder samples varied from 15.48 percent to 15.50 percent (db), respectively as an effect

of temperature rise from 50˚C to 80˚C in the study range. Similar results were observed by Ahmed *et al.,* (2013), who reported that the ash content of *Aloe vera* powder was 16.88±0.04 percent. Gautam and Awasthi (2007) also reported 14 percent ash content in the whole leaf *Aloe vera* powder samples obtained after try drying at 50˚C.

5. Fiber

Table 4 (e) shows the fiber content of *Aloe vera* powder. Fiber content varied for *Aloe vera* powder ranged was 14.98±1.38 (%), 15.85±0.71 (%) and 14.92±2.65 (%) at 45˚C, 55˚C and 65˚C respectively. Highest fiber content is observed at 55˚C drying temperature *Aloe vera* powder. There is as such no trend was observed in the fiber content w.r.t. the increase in temperature. The change in fiber content was significant at p≤0.01. Gulia *et al.* (2010) reported that fiber content in the *Aloe vera* powder sample ranged from 17.86 to 17.92 percent after hot air drying from 50˚C to 80˚C respectively. The results are in similar line with the reported value of the crude fiber 18.5 percent (Gautam and Awasthi, 2007).

6. Carbohydrate

Table 4 (f) shows the carbohydrate content of *Aloe vera* powder. Carbohydrate content varied for *Aloe vera* powder ranged was 54.68±1.71 (%), 52.98±1.82 (%) and 54.97±2.75 (%) at 45˚C, 55˚C and 65˚C respectively. Highest carbohydrate content observed at 65˚C drying temperature *Aloe vera* powder. The increase in carbohydrate content with an increase in temperature was significant at p≤0.01. Haque *et al.* (2014) noticed that 56.27 per cent carbohydrate content in *Aloe vera* powder.

7. Bulk density

Table 4 (g) shows the bulk density for *Aloe vera* powder. Bulk density varied for *Aloe vera* powder ranged was of 0.48±0.01, 0.49±0.01 and 0.45±0.01 for 45˚C, 55˚C and 65˚C respectively. Highest bulk density observed at 55˚C *Aloe vera* powder. The variation in bulk density of *Aloe vera* powder was significant at p≤0.01.

8. Water absorption capacity

Table 4 (h) shows the water absorption capacity content for *Aloe vera* powder. Water absorption capacity varied for *Aloe vera* powder ranged was 1.34±0.06 (g/ml), 2.22±0.27 (g/ml) and 2.35±0.50 (g/ml) respectively. Highest water absorption capacity observed at 65˚C of *Aloe vera* powder. The increase in water absorption capacity was significant at p≤0.01. Olua *et al.* (2015) noticed that the 1.200±0.00 (g/ml) of water absorption capacity for cashew apple powder respectively. Banupriya *et al.* (2016) reported that wood apple seed powder contained 2.28+0.01 (g/ml) water absorption capacities.

9. wettability

Table 4(i) shows the wettability for *Aloe vera* powder. Wettability varied for *Aloe vera* powder ranged from 35.00±1.0 sec to 36.67±0.58 secat drying temperature increase from 45˚C to 65˚C respectively. Highest wettability observed at drying temperature of 65˚C of *Aloe vera* powder. The change in wettability at varied temperature of drying was significant at p≤0.01. Similar results was observed by Gulia *et al.* (2010) who reported that the wettability of *Aloe vera* powder ranged was 35 to 37(sec) at 50, 60, 70 and 80˚C respectively.

10. Colour

Table 4 (j) shows the colour for *Aloe vera* slice powder dried at 45, 55 and 65˚C. L value for 45˚C, 55˚C and 65˚C was 67.08±0.38, 66.89±0.27 and 55.29±0.95 respectively, a value for 45˚C, 55˚C and 65˚C was 2.52±0.02, 4.04±0.03 and 2.11±0.17 respectively and b value for 45˚C, 55˚C and 65˚C was 28.58±0.47, 30.53±0.32 and 27.72±0.27.

CONCLUSION

1. Moisture content of *Aloe vera* slices powder at 45˚C, 55˚C and 65˚C was 4.88±0.02 (%), 5.55±0.05 (%) and 5.23±0.06(%).
2. Convective hot air drying of *Aloe vera* slices powder from the 4684.689 to 7.388% (db), 1372.754 to 8.603% (db) and 1236.89 to 9.319835%

(db) had taken the 33 h, 19 h and 12 h for drying at 45, 55 and 65°C respectively.

3. Hot air tray drying of *Aloe vera* slices powder indicated that Modified page model was fitted well to the experimental data. The characteristics constants of Modified Page model are k = 0.037 with R^2 = 0.9683 and *RMSE = 0.00088*.

4. Activation Energy needed for the moisture movement from the *Aloe vera* slices powder during drying was found to be 0.6664 kg/mole**.**

5. The results obtained that the protein was decreases from 7.10±0.03 to 5.57±0.03, fat was decreases from 2.02±0.12 to 1.97±0.10, ash increases from 16.33±0.29 to 17.33±0.29, fiber decreases was from 14.98±1.38 to 14.92±2.65, carbohydrates was increases from 54.68±1.71 to 54.97±2.75, bulk density decreases from 0.48±0.01 to 0.45±0.01, water absorption capacity increases from 1.34±0.06 to 2.35±0.50 and wettability increases from 35.00±1.00 to 36.67±0.58 respectively when the temperature of drying increasesform 45 to 65°C.

NOMENCLATURES

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
D_{eff}	Effective diffusivities, m2/s
R^2	Radius, m

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