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Research Paper

Effect Temperature of Convective Hot Air Drying of Jackfruit Seed on Physico-chemical and Functional Properties of Jackfruit Seed Flour

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ABSTRACT

The study was conducted to analysis of physico-chemical properties of jackfruit seed flour. Jackfruit seed flour prepared from the drying temperature 50 °C, 60 °C, and 70 °C. Jackfruit seed were dried in a convective hot air dryer at 50°C, 60°C and 70°C. The air velocity inside the dryer was 2-3 m/s, the drying process completed within 38 hrs, 27hrs, and 19hrs time to dry the product at 50 °C, 60 °C, and 70 °C. Drying rate increased with increase in air temperature. The experimental drying data of Jackfruit seed were applied to three Moisture ratio models, namely, the Newton, Page and Henderson and Pabis. Among all the models, the Henderson and Pabis Model was found to be the best for explaining the drying characteristics of Jackfruit seed. The effective moisture diffusivity varied from 2.174×10^{-8}, 3.565×10^{-8} and to 6.261×10^{-8} and over the temperature range studied, with activation energy of 46.646 kJ/mol for Jackfruit seeds. The jackfruit seed flour contains moisture 6.33 to 7.81 %, protein 12.07 to 7.17 %, fat 1.75 to 1.25%, fibre 2.32 to 2.75 % carbohydrate 75.32 to 80.52%, ash 2.21 to 1.1 %. The flour had average of water absorption capacity (2.374ml/ g), oil absorption capacity (2.081ml/g) were recorded.

Keywords: Jackfruit seed flour, effective moisture diffusivity, activation energy, Physico chemical and functional properties

Jackfruit (*Artocarpus heterophyllus L.*) belongs to the family *Moraceae*. Jackfruit is tropical fruit native to India, Bangladesh, Thailand and Indonesia and is now found in many parts of Asia, Africa, South America and Northern Australia. In India, the jackfruit grows in different parts of the country, including the southern states, Assam, Bihar and central Himalayas, Uttar Pradesh, Maharashtra, Kerala, Tamil Nadu and Karnataka (Wangchu *et al.* 2013) and considered to be 'Poor man's food' (Jagadeesh *et al*. 2007; Prakash *et al.* 2009). In South India the jackfruit is popular food making next to Mango and Banana (Baliga *et al.* 2011; Morton 1987). The total area under jackfruit cultivation is around 32,600 ha (Butool *et al*. 2013).

The average weight of a fruit is 3.5 to 10 kg. Jackfruit consists about 29% pulp, 12% seed, and 54% rind (Eke- Ejiofor, 2014; Berry and Kalra 1988). Ripe jackfruits are large sized fruits measuring between 22-90 cm in length and 13-50 cm width with weight ranging from 2-35 kg. The fruit may contain between 100 and 500 seeds (Sindhu, 2012)

A single jackfruit seed is enclosed in a white aril encircling a thin brown spermoderm, which covers the fleshy white cotyledons are fairly rich in starch and protein (Singh *et al*. 1991). Seed make up

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around 10-15% of the total fruit weight and have high carbohydrate contents, dietary fibre, vitamins, minerals and phyto-nutrients. The seeds are light brown in colour, oval or oblong ellipsoid or rounded shape, 2-3 cm length and 1-1.5 cm in diameter, seeds of the ripe fruit have around 55% (wb) moisture and therefore do not keep well for long duration. The Jackfruit seeds being seasonal and perishable need proper processing protocol for its increasing the shelf life. Generally seeds are utilized as boiled in sugar and eaten as dessert (Roy *et al.* 1995) or baked and restricted to domestic usage. Jackfruit seed contains Lignans, isoflavin, saponin, all phytonutrients and their health benefits are wide ranging (Swami *et al*. 2012).

Composition of Jackfruit seed flour depends on nature of the seeds, protein, carbohydrates, ash, fat, crude fibre contents 31.9% and 66.2% , 2.72%,.1.25%, 3.09% (Bobbio *et al.* 1978; Khan *et al.* 2016).

Drying is the one of the oldest and a very important unit operation, It involve the application of heat to a material which results in transfer moisture within the material to its surface then water removal from surface of the material to the atmosphere (Ekechukwu 1999, Akpinar and Bicer 2005). It is most frequent method of food preservation and increases shelf life and product quality. After drying seeds can be utilised for longer duration which can be utilise by converting seeds into flour. Jackfruit seed flour used for making alternative product such as cookies, cake, bread, biscuit, thickening and stabilizing agent.

Various Mathematical Models have been fitted to the experimental data was observed in the literature for Pumpkin seed, Tomato seeds, Pear seeds, Okra, Soybean grain, Coca, Cocoa bean, Kokum rind, Oyster mushroom, Finger millet by Jittanit (2011), Sogi *et al.* (2003), Motri *et al.* (2013), Honore *et al.* (2014), Coradi *et al.* (2016), Hii *et al.* (2009), Ndukwu *et al.* (2012), Hande *et al.* (2014), Bhattacharya *et al.* (2013), Radhika *et al.* (2011) but Models on the Jackfruit seed is not available. Present study is aimed to study the drying characteristics of Jackfruit seed at varied temperature. Various Models were fitted to experimental data on the moisture ratio with respect to time. The nutritional and Physical qualities (moisture, protein, fat, fibre, carbohydrate, ash) and functional properties (colour, water absorption, oil absorption, bulk density) of the jackfruit seed flour were also been determined.

MATERIALS AND METHODS

Jackfruit seed was purchased from Jackfruit processing industry, Kudal, Dist. Sindhudurga. The Jackfruit seeds were cleaned, washed, remove fleshy white cotyledon and dried at 50 °C, 60 °C, and 70 °C in a convective hot air dryer.

Drying of Jackfruit seeds

1. Convective hot air drying

Convective hot air drying of Jackfruit seeds was performed at Department of Post-Harvest Engineering, Post Graduate Institute of Post-Harvest Management, Killa-Roha. The drying was carried out in the convective hot air dryer (Make M/s. Sagar Industries Kudal: India) having capacity of 5 kw. There were nine numbers of trays inside the convective hot air dryer. The size of the tray was 81cm x 41cm x 3.4 cm. The seeds were spread on the tray in single layer. The mesh (square) size of the tray was 1x1 mm. The temperature of the drying was 50°C, 60°C and 70°C. The weight loss with respect to the time was recorded from trays at different location in the convective hot air dryer. The moisture content with respect to the time was calculated from drying data. The drying data includes initial moisture content; weight loss, average moisture content with respect the time, drying rates, moisture ratios, and final moisture content of Jackfruit seed was recorded. Three replications were taken for each experiment.

2. Drying rate

The drying rate of Jackfruit seeds was calculated on dry basis using following formula (Chakraverty, 2005).

$$R = \frac{W_r}{T \times W_d} \times 100 \qquad \ldots(1)$$

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)

3. Moisture ratio

The moisture ratio of Jackfruit seeds was calculated on dry basis using following formula (Chakraverty, 2005).

$$\text{Moisture ratio} = \frac{M - M_e}{M_0 - M_e} \quad \ldots(2)$$

Where,

MR = Moisture ratio

M_0 = Initial moisture content, %(db)

M_e = equilibrium moisture content, % (db)

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

The root mean square error was for the best fit of the model was determined for higher R^2 values and lower MSE.

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

Where,

MR_{exp} = experimental moisture ratio

MR_{pre} = predicted moisture.

N and n = number of observations, number of constant (Togrul and Pehlivan, 2004).

4. Drying model

Moisture Content (%db) versus drying time (min) and drying rate (g of water removed / 100 g bone dry material / min) with respect to moisture content was determined for drying of Jackfruit seeds. Moisture ratio versus drying time (min) was also determined from the experimental data.

Table 1: Mathematical model tested with the moisture ratio of Jackfruit seeds

Sl. No.	Model	Equation	Reference
1	Newton	MR = exp (-kt)	El- Beltagy *et al.* (2007)
2	Page	MR = exp ($-kt^n$)	Page (1949)
3	Henderson and Pabis	MR = a.exp (-kt)	Henderson and Pabis (1961)

Various mathematical models listed in Table 1 were tested on the experimental data on moisture ratio versus drying time in minute of Jackfruit seed with convective hot air drying the moisture ratio determines the unaccomplished moisture change defined as the ratio of free water still to be removed, at time t over the initial total free water (Henderson and Pabis, 1961).

5. Correlation regration coefficient and error analysis

The goodness of fit of the tested mathematical models to the experimental data was evaluated with the correlation coefficient (r^2), chi-square (χ^2) and the equation (4). The higher the r^2 value and lower the chi-square (χ^2) equation (4) and lower value of RMSE values, the better is the goodness of fit (Ozdemir *et al*. 1999; 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.

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

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.

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

6. Effective moisture diffusivity

The Fick's second law can be used to describe the drying process of Jackkfruit seeds. In general series solution of Fick's second law in spherical co-ordinates on jackfruit seed with spherical with radious 28.6 mm. Effective diffusivity of Jackfruit seeds can be calculated by using Fick's second law of diffusion equation (Doymaz and Pala, 2003) given equation (5);

$$MR = \frac{6}{\pi^2}\sum_{n=1}^{\infty}\frac{1}{n^2}exp(-t\ \frac{n^2.\pi^2 D_{eff}}{R^2}) \quad \ldots(5)$$

Where,

R^2 = equivalent radius of jackfruit seed to be dried, m

n = positive integer

D_{eff} = effective diffusivity, (m^2/s)

t = time, min

For long drying times, equation (6) can be simplified in straight line equation. The effective diffusivity determined using the method of slopes as discussed by (Ojediran and Raji 2010);

$$Ln(MR) = \frac{-6\times t\times D_{eff}}{R^2} \quad \ldots(6)$$

The effective diffusivity can be determined from the slope of equation (7) (Sacilik, 2007);

$$Effective\ diffusivity\ \left(D_{eff}\right) = \frac{R^2K}{\pi^2} \quad \ldots(7)$$

7. Activation energy

The effect of temperature dependence of the effective moisture diffusivity is generally described using Arrhenius type relationship to obtained better agreement by Suarez *et al.* (1980) and Roberts *et al.* (2008).

$$D_{eff} = D_o exp\left(-\frac{E\alpha}{RT}\right) \quad \ldots(8)$$

Where,

D_o = diffusivity constant or Arrhenius pre- exponential factor (m^2/s); Ea = activation energy (kJ/ mol); R = universal gas constant (kJ/ mol K); T = air temperature (°K).

The pre exponential factor of the Arrhenius equation and corresponding activation energies were determined by using the data of effective moisture diffusivities and absolute air temperature

Sample preparation

The dried Jackfruit seeds were grounded into powder of size 4.885×mm in hammer mill were used . (Make: M/ Sagar Engineering work, Kudal (India).

Physico chemical analysis of jackfruit seed flour

1. Moisture content

The moisture content of the sample Jackfruit seed flour prepared by dried seed at 50, 60 and 70˚C determined by AOAC (2010). 15 g of the Jackfruit seed flour was taken for in to each three different moisture boxes. The initial weight of 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 sample were determined by equation (9);

$$\text{Moisture content \% (db)} = \frac{W_1 - W_2}{W_2}\times 100 \quad \ldots(9)$$

Where,

W_1 = weight of sample before drying, g

W_2 = weight of sample after drying, g

2. Protein

Protein content in the sample jackfruit seed flour prepared by dried seed at 50, 60 and 70^0C was determined by a micro-Kjeldahl distillation method (AOAC, 1990). The samples were digested by heating with concentrated sulphuric acid (H_2SO_4) in the presence of digestion mixture, potassium sulphate (K_2SO_4) and copper sulphate (C_uSO4). The mixture was made alkaline with 40% NaOH. Ammonium sulphate thus formed. Released ammonia which was collected in 4% boric acid solution and titrated again with standard HCL. The per cent nitrogen content of the sample was calculated by the formula given below.

$$\% (N) = 1.4 \times (\text{ml HCl} - \text{ml blank}) \times \text{Conc. of } \frac{HCL}{Weight} \text{ of sample (g)} \quad \ldots(10)$$

% Protein = % N × Factor (6.25).

3. Fat (%)

Fat contain of sample jackfruit seed flour prepared by dried seed at 50, 60 and 70^{0}C was determined using soxhlet fat extraction system (AOAC, 2010). In this method, initially weight of empty flask was weighed. 2g of sample jackfruit seed flour was wrapped in filter paper and was kept in siphoning tube and condenser was fixed above it and siphoned for 9 to 12 times with the petroleum ether in soxhlet apparatus. After removing assembly, evaporation of petroleum ether was allowed by heating round bottom flask. Residue reminder at the bottom of the flask and was reweighed with flask. The quantity of residue was determined as fat content of jackfruit seed flour. Fat content was calculated by using equation (11);

$$\% \text{ Fat} = \frac{\text{Final weight(g)} - \text{Initial weight(g)}}{\text{Weight of sample(g)}} \times 100 \quad \ldots(11)$$

4. Fiber (%)

Fiber contain of sample jackfruit seed flour prepared by dried seed at 50, 60 and 70^{0}C was determined using about 2 – 5 g of moisture and fat free sample was weighed into a 500 ml beaker and a 200 ml of boiling 0.25 N sulphuric acid was added to the mixture and boiled for 30 min keeping the volume constant by addition of water at frequent intervals. The mixture was filtered through a muslin cloth and then transferred to the same beaker and 200 ml of boiling 0.31 N (1.25 %) NaOH was added. After boiling for 30 min, the mixture was filtered through muslin cloth. The residue was washed with hot water till it is free from alkali, followed by washing with alcohol and ether. It was then transferred to crucible, dried overnight at 80°C to 100°C and weighed. The crucible was heated in muffle furnace at 525°C for 2 – 3 hrs, cooled and weighed again. The difference in the weights represented the weight of crude fibre, Rangana (1986).

$$\text{Crude Fiber} \left(\frac{g}{100g}\right) = \frac{100 - (\text{Moisture} + \text{Fat}) \times \text{Weight of Fiber weight}}{\text{Weight of sample taken } (\text{Moisture} + \text{Fat free sample})} \times 100 \quad \ldots(12)$$

5. Ash (%)

Ash content of sample jackfruit seed flour prepared by dried seed at 50, 60 and 70^{0}C was calculated using muffle furnace. 5 gram of jackfruit seed flour prepared by dried seed at 50, 60 and 70^{0}C was taken in crucible. Weight of crucible and flour was recorded and kept in muffle furnace at 525 °C for 4 -5 hrs till constant weight was achieved. The crucible was cooled in desiccators and final weight of ash and crucible was recorded. Ash content was calculated by using equation (14).

$$\text{Ash content (\%)} = \frac{(W_2 - W_1)}{(\text{Weight of sample})} \times 100 \quad \ldots(13)$$

Where,

W_2 = weight of crucible + ash,

W_1 = weight of empty crucible

6. Carbohydrates (%)

The carbohydrate content of Jackfruit seed flour prepared by dried seed at 50, 60 and 70°C were calculated from protein, fat, fiber, ash and moisture content (Adegunwa *et al*. 2012);

$$\text{Carbohydrates} = 100 - (\text{protein} + \text{fat} + \text{fiber} + \text{ash} + \text{moisture content}) \quad \ldots(14)$$

7. Water absorption capacity

Water absorption of samples jackfruit seed flour prepared by dried seed at 50, 60 and 70°C was determined using the method of Sosulski (1962) with slight modifications. The 3 g sample was dispersed in 25ml of distilled water and placed in pre weighed centrifuge tubes. The dispersions was stirred occasionally. After a holding period of 30 min, the dispersions were centrifuged at 5000 rpm for 25 min. The supernatant was removed and the pellet was dried at 50°C for 25 min which was cooled and weighed. The water absorption capacity was expressed as grams of water retained in the material. The experiment was repeated for three times and average reading was reported. The water absorption capacity calculated using equation (15).

$$WAC = \frac{W_2 - W_1}{W_0} \times 100 \quad \ldots(15)$$

Where,

W_0 = The weight of sample, (g)

W_1 = The weight of centrifuge tube plus sample, (g)

W_2 = The weight of centrifuge tube plus sediments

8. Oil absorption capacity

Oil absorption capacity (OAC) of samples jackfruit seed flour prepared by dried seed at 50, 60 and 70^{0}C was determined using the method of AOAC (2005). About 1 g of the sample was weighed into pre-weighed 15 ml centrifuge tubes and thoroughly mixed with 10 ml of refined pure groundnut oil using vortex mixer. Samples were allowed to stand for 30 min. The sample-oil mixture was centrifuged at 3000 rpm for 20 min. immediately after centrifugation, the supernatant was carefully poured into a 10 ml graduated cylinder, and the volume was recorded. The Oil absorption capacity calculated using equation (16).

$$OAC = \frac{W_2 - W_1}{W_0} \times 100 \quad \ldots(16)$$

Where,

W_0 = The weight of sample, (g)

W_1 = The weight of centrifuge tube plus sample, (g)

W_2 = The weight of centrifuge tube plus sediments, (g)

9. Bulk density (g/ml)

Bulk density was evaluated by 10 ml measuring cylinder bound on the weight and volume of sample of jackfruit seed flour were poured into a graduated cylinder, gently tapped ten times and filled to 10 ml results were expressed as g/ml (Mandge *et al.* 2014).

$$\text{Bulk density (g/ml)} = \frac{\text{Wt. of Cylinder + Sample (g)} - \text{Wt. of empty Cylinder (g)}}{\text{Volume of Sample filled (ml)}} \quad \ldots(17)$$

10. Colour

Colour of Jackfruit seed flour at 50ºC, 60ºC, and 70°C was measured by using Konica Minolta colour Reader. (Make: Minolta Camera Co. Ltd. Japan Model: (R-10). The colour of the Jackfruit seed flour was measured in dark room. Jackfruit seed flour at 50°C, 60°C, and 70°C was placed on white surface and placing colour reader on the flour sample in a Petri dish and the colour was measured in *L, a, b* were reported. Where L value indicates degree of lightness or darkness, '*a*' value indicates redness or greenness and '*b*' value indicates the yellowness or blueness.

RESULTS AND DISCUSSION

Convective hot air drying of Jackfruit seeds

Fig. 1 shows moisture content (db) % with respect to time (min) of Jackfruit seeds dried by convective hot air dryer. The jackfruit seeds were dried from average initial moisture content of 124.41% (db) to 4.048% (db) at 50 °C; 123.22 % (db) to 3.267 % (db) at 60 °C; 125.48 to 3.303% (db) at 70 °C respectively. It took around 38 hrs, 27hrs, and 19 hrs time to dry the product at 50 °C, 60 °C, and 70 °C. The initial drying rate of Jackfruit seeds was 0.231g, of water removed /100 g of bone dry matter per minute and decrease up to the 0.053 g of water removed/ 100g of bone dry matter per minute at 50 °C; 0.435 g of water removed /100 g of bone dry matter per minute and decreases up to the 0.072 g of dry matter at 60 °C; 0.531 g of water removed /100 g of bone dry matter per min and decreases up to the 0.107 g of water removed / 100 g of dry matter at 70 °C.

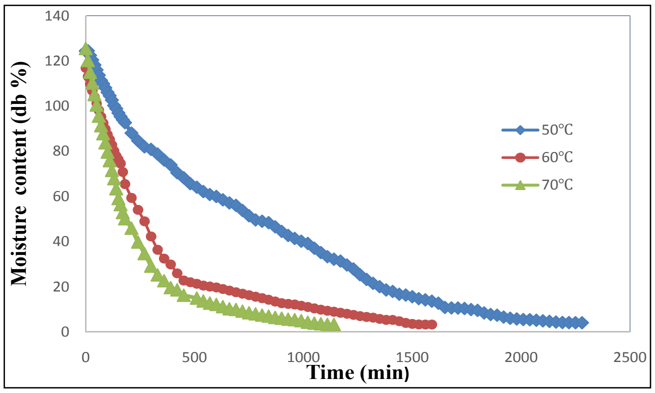

Fig. 1: Moisture content % (db) versus time (min) by convective hot air drying at different temperature for Jackfruit seeds

From Fig. 2 it was observed that the drying took place in falling rate period. As the temperature of drying increases from 50 °C, 60 °C and 70 °C the drying rate also increases. Moisture removal inside the Jackfruit seeds at 70°C was higher and faster than the other investigated temperature. Migration of surface moisture and evaporation rate from the surface to the air decreases with decrease of the moisture in the Jackfruit seed. The shorter time of drying was observed at higher temperature thus increased drying rate.

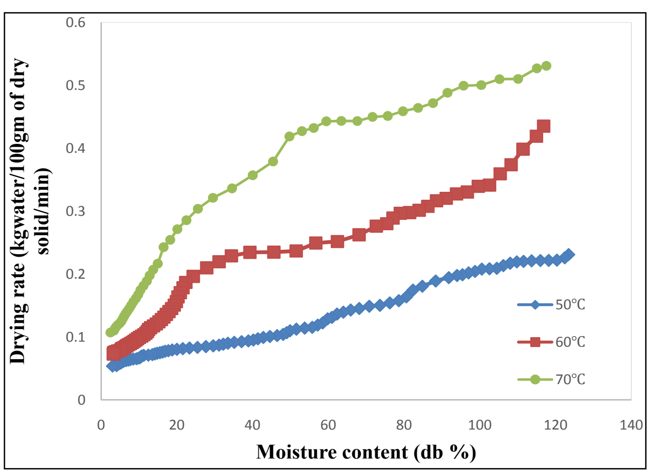

Fig. 2: Drying rate (g water removed/100 g of bone dry material/min) versus moisture content % (db) of Jackfruit seeds dried by convective hot air drying method at different drying temperature

Fig. 3 shows variation in moisture ratio with respect to time in minute. During the drying experiment moisture ratio decreases from 1 to 2.24 × 10^{-4}, 1 to 2.35 × 10^{-4} and 1 to 2.55 × 10^{-3} at the drying temperature of 50°C, 60°C and 70°C respectively. The results obtained were in agreements with those reported by (Radhika *et al.* 2011).

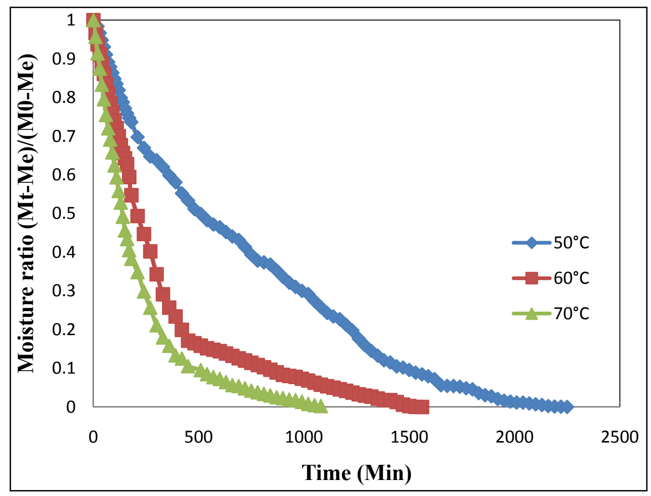

Fig. 3: Variation in moisture ratio with respect to time, min for Jackfruit seed during convective hot air drying

Evaluation of thin layer drying model of Jackfruit seeds dried by convective hot air drying

The Table 2(a), 2(b) and 2(c) shows the model parameters of various model fitted to the experimental data for Newton model, Page model, Henderson and Pabis, at 50°C, 60°C and 70°C by convective hot air drying of Jackfruit seed. Among the models fitted to the experimental data at 50°C, 60°C and 70°C the Henderson and Pabis model was well fit-ted to the experimental data with $R^2 \geq 0.989$; MSE≤ 1.85 × 10^{-4} and chi square (χ^2) ≥ 8.91 × 10^{-3} Non-Linear regression analysis was done according to the three thin layer models for moisture ratio data.

Table 2(a), 2(b), and 2(c) shows the statistical regression results of the different models, including the drying model coefficients and comparison criteria used to evaluate goodness of the fit including the R^2, and RMSE of Jackfruit seeds at different temperature. In all cases R^2 values for the models were greater than 0.989 indicating model is well fitted. The model parameter i.e. 'k' 1.37 × 10^{-3}, 3.31 × 10^{-3} and 5.01 × 10^{-3} at 50°C, 60°C and 70°C respectively. Value 'a' was 0.986, 1.013, and 1.010 for the 50°C, 60°C and 70°C respectively. The 'k' value increases with in-crease in temperature from 50°C to 70°C

Table 2: Model parameters, R^2, RMSE and Chi squre values of Jackfruit seeds dried by Convective hot air drying at 50 °C, 60 °C, 70 °C

Table 2 (a): Convective hot air drying at 50°C temperature

Sl. No.	Model name	Temperature 50 °C			
		Model Parameters	R^2	MSE	χ^2
1	Newton	k=1.39×10^{-3}	0.9888	1.25×10^{-3}	1.10×10^{-1}
2	Page	k=1.28×10^{-3} n=1.011	0.9888	1.26×10^{-3}	1.09×10-1
3	Henderson and Pabis	a=0.986 k=1.37×10^{-3}	0.9894	1.23×10^{-3}	1.07×10^{-1}

Table 2 (b): Convective hot air drying at 60°C

Sl. No.	Model name	Temperature 60°C			
		Model Parameters	R^2	MSE	χ^2
1	Newton	k=3.25×10^{-3}	0.9942	6.37×10^{-4}	4.14×10^{-2}
2	Page	k=3.18×10^{-3} n=1.003	0.9943	6.47×10^{-4}	4.14×10^{-2}
3	Henderson and Pabis	a=1.013 k=3.31×10^{-3}	0.9946	6.29×10^{-4}	4.03×10^{-2}

Table 2 (c): Hot air drying at 70°C

Sl. No.	Model name	Temperature 70°C			
		Model Parameters	R^2	MSE	χ^2
1	Newton	k=4.93×10^{-3}	0.9982	1.93×10^{-4}	9.47×10^{-3}
2	Page	k=4.86×10^{-3} n=1.002	0.9982	1.97×10^{-4}	9.46×10^{-3}
3	Henderson and Pabis	a=1.010 k=5.01×10^{-3}	0.9984	1.85×10^{-4}	8.91×10^{-3}

Effective moisture diffusivity of Jackfruit seed dried by convective hot air drying

Fig. 4 shows Ln (MR) versus time (minute) for convective hot air drying of jackfruit seed dried at 50°C, 60°C and 70°C respectively. The graph shows the straight line curve. The straight line equation $y = mx + c$ where the m is the slope of line. Effective diffusivity (D_{eff}) at time for jackfruit seeds which was calculated by Eq (6). Table 5 shows the effective diffusivity of jackfruit seeds dried at 50°C, 60°C and 70°C. The diffusivity values were in the range of 2.174 × 10^{-8} to 6.261 × 10^{-8} for all the temperature. As the temperature increases the diffusivity value increases from 2.174 × 10^{-8}, 3.565 × 10^{-8} and 6.26 × 10^{-8} at 50°C, 60°C and 70°C respectively. The effective diffusivity used to explain the mechanism of moisture movement during drying.

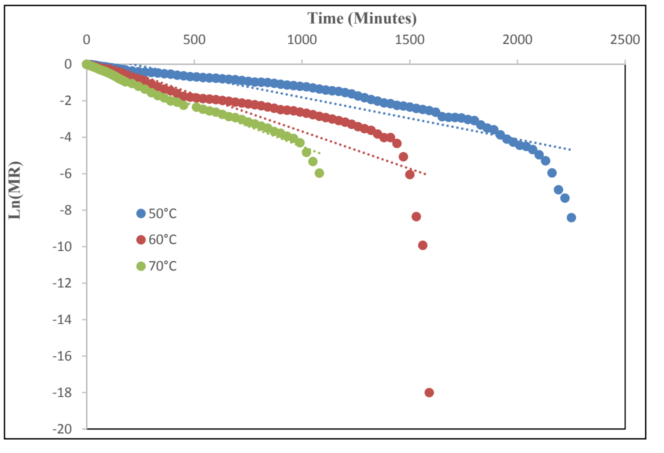

Fig. 4: Ln(MR) versus time, minute for Jackfruit seeds dried at varied temperature

It was observed that D_{eff} values increased greatly with increase in 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). The values obtained of effective diffusivity from this study was 2.174 × 10^{-8}, 3.565 × 10^{-8}, and 6.26 × 10^{-8} during the drying temperature of 50°C, 60°C and 70°C respectively. The values of obtained from this study lies within the general range of for drying of local tomato variety was 1.17- 3.51 × 10^{-8} to 1.25- 3.13 × 10^{-8} m^2/s reported by

Jaiyeoba and Raji (2012), D_{eff} for squash seed drying was 0.160×10^{-9} and 0.551×10^{-10} m^2 /s respectively, reported by Reza *et al*. (2013); 4.76×10^{-9} to 8.32×10^{-9} m^2/s for apricot reported by Togrul and Pehlivan, (2004) at 50°C, 60°C, 70°C and 80°C. Onion Slices in the drying air temperature range was 30 °C to 60 °C and 3.4910^{-8} to 9.4410^{-8} reported by Demiray *et al.* (2016) respectively.

Activation energy for jackfruit seed dried by convective hot air drying

Fig. 5 shows the Ln (D_{eff}) vs 1/ for dried jackfruit seed at 50 °C, 60 °C, and 70 °C. The activation energy was calculated by plotting of *Ln* (D_{eff}) vs. reciprocal of absolute temperature showed straight line in the range of air temperature studied. The activation energy (*Ea*) for moisture diffusion calculated from the slope of straight lines graphs are given in Table (5).

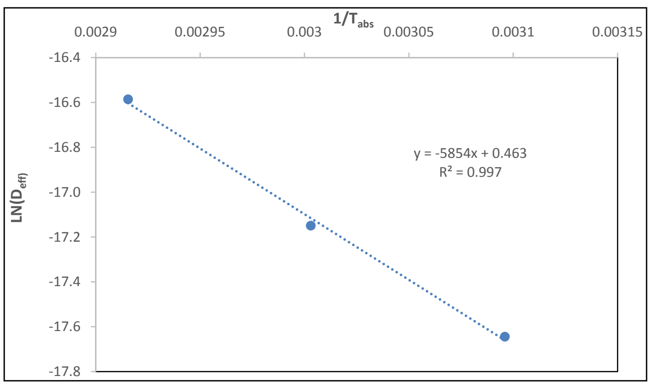

Fig. 5: *LnDe*$_{ff}$ vs 1/T_{abs} of jackfruit seed drying by convective hot air drying method

Table 5: Values of effective diffusivity and activation energy of jackfruit seed at different temperature

Temperature	(m^2/s)	Ea (kJ/mole)
50 °C	2.174×10^{-8}	
60 °C	3.565×10^{-8}	46.646
70 °C	6.261×10^{-8}	

The activation energy for moisture diffusion was found to be 46.646 kJ/mole. The energy of activation (Ea) are reported in the literature, 45.39 and 47.79 kJ/mole for fruit and *Cladode opunita ficus indica* (Amira *et al.* 2014); 31.94 and 34.49kJ/mol for temperature 50 to 80°C, for squash seed (Reza *et al.* 2013), 62.12 kJ/mol for the Pumpkin seeds which was reported by (Jittanit w., 2011).; 42.35 kJ/mol for peas (Senadeera *et al.* 2003).

The results indicated a linear relationship between (Ln D_{eff}) and (1/T_{abs}) as plotted in Fig. 5 for jackfruit seeds dried by convective drying at 50 °C, 60 °C and 70 °C. The diffusivity constant or pre- exponential factor of Arrhenius equation (D_o) and activation of energy (*Ea*) calculated from the linear regression are 1.589 m^2/s and 46.646 kJ/mol for jackfruit seed

Physico chemical and Functional Properties of Jackfruit seed Flour

Table 6 shows the physico-chemical and functional properties of Jackfruit seed flour such as Moisture (%), Protein (%), Fat(%), Fibre(%), Carbohydrates (%), Ash (%), Water absorption capacity(g/ml), Oil absorption capacity (g/ml), Bulk density(g/ml), Colour (*L**), (*a**), (*b**) for Jackfruit seed flour dried at 50 ^{0}C, 60 ^{0}C and 70 ^{0}C respectively.

1. Moisture (%)

Table 6 (a) shows moisture content of fresh Jackfruit seed and Jackfruit seed dried at 50°C, 60°C and 70°C. Moisture content for Jackfruit seed was 55.41±0.205 has and the moisture content varied for jackfruit seed flour in the range was 6.41-7.3% and 6.55- 7.81% average was 6.41 ±0.062, 7.04±0.051, 7.37±0.71 at drying temperature 50°C, 60°C, 70°C respectively. The moisture content of fresh jackfruit seed reported in the literature was 51.0 to 64.5 by Vazhacharickl *et al.* (2015) and Jagtap and Bapat (2010). The results of moisture content of jackfruit seed flour are in general agreement with the result obtained by Banerjee *et al*. (2015) and Abraham and Jayamuthunagai, (2014) reported that moisture content 6.09 % and 7.7% respectively.

2. Protein (%)

Table 6 (b) shows that Protein content of fresh Jackfruit seed and Jackfruit seed flour. Protein

Table 6: Physico- chemical and functional properties of Jackfruit seed flour

Sl. No.	Parameter	Fresh jackfruit seed	Jackfruit seed flour			$SE_{\pm}$ at	CD at
			50 °C	60 °C	70 °C	P≤0.05	P≤0.05
(a)	Moisture (%)	55.41±**0.205**	6.41±0.062	7.29±0.451	7.3±0.715	0.117	0.406
(b)	Protein (%)	7.75±**0.270**	11.6±0.438	9.39±0.265	7.09±0.525	1.363	4.719
(c)	Fat (%)	1.71 ±0.03	1.66±0.076	1.48±0.076	1.21±0.029	8.944	46.895
(d)	Fibre(%)	1.34 ±0.110	2.83±0.055	2.52±0.021	2.27±0.062	11.651	40.317
(e)	Ash(%)	1.25 ±0.221	2.10±0.100	1.15±0.235	1.12±0.020	3.900	13.49
(f)	Carbohydrate (%)	33.61 ±0.226	75.4±0.496	78.25±0.721	81.02±0.933	0.781	2.704
(g)	Water absorption capacity (g/ml)		2.1±0.035	2.3±0.059	2.5±0.047	0.429	1.485
(h)	Oil absorption Capacity (g/ml)		1.7 ±0.543	2.1±0.053	2.3±0.042	33.96	6.323
(i)	Bulk density (g/ml)		0.7±0.071	0.78±0.026	0.68 ±0.064	10.14	35.11
(j)	Colour L*	129.04±0.511	95.48±0.017	99.72±0.01	107.9±0.038	23.35	80.818
	a *	3.95±0.705	5.11±0.012	5.430±.025	3.99±0.010	33.96	117.54
	b *	26.63±0.168	18.71±0.127	26.15 ±2.327	22.52±0.015	0.429	1.485

content for Jackfruit seed was 7.756±0.270 and protein content varied for Jackfruit seed flour ranged was 7.9 – 11.6 % at 50 °C, 60 °C and 70 °C respectively. The average protein content was 11.6±0.43, 9.39±0.26 and 7.09±0.52 at drying temperature 50 °C, 60 °C and 70 °C respectively. The protein content of fresh jackfruit seed reported in the literature was 6.6 to 7.04 by Jagtap and Bapat (2010). The highest protein content was observed at 50 °C drying temperature of Jackfruit seed flour. The protein content decreases with increase in drying temperature from 50 °C to 70 °C. The decrease in protein was significant at p≤0.05. The protein content of Jackfruit seed flour reported in literature was 9.19 – 11.34,13.49 reported by Noor *et al.* (2014) and Jayamuthunagai (2014).

3. Fat (%)

Table 6 (c) shows that Fat content of fresh jackfruit seed and Jackfruit seed flour. Fat content for fresh Jackfruit seed was 1.71±0.03. Fat content varied for Jackfruit seed flour ranged from 1.21 to 1.66%. The average fat content of jackfruit seed flour was 1.66±0.076, 1.4±0.076 and 1.2±0.029 at drying temperature 50 °C, 60 °C and 70 °C. Fat content was highest at drying temperature at 50 °C of jackfruit seed flour. The decrease in fat was significant at p≤0.05. The fat content of fresh jackfruit seed reported in the literature was 0.40 to 043 by Jagtap and Bapat (2010), Banergee *et al.* (2015). Similar results of fat content of jackfruit seed flour reported by Noor *et al*. (2014) ranged 1.18 to 1.40 among different varieties of Jackfruit; Babbio *et al*. (1978) reported 1.3 per cent fat content and Khan *et al.* (2016) reported 1.25% of fat for jackfruit seed flour.

4. Fibre (%)

Table 6 (d) shows that fibre content of fresh jackfruit seed and jackfruit seed flour. Fibre content of fresh Jackfruit seed was 1.34% and fibre content for Jackfruit seed flour was observed in the range of 2.27- 2.83%, the average fiber content was observed 2.837±0.055, 2.527±0.021 and 2.27±0.062 at 50 °C, 60 °C and 70 °C respectively. The decrease in fibre was significant at p≤0.05. The fibre content of fresh jackfruit seed reported in the literature was 1.to 1.5 by Jagtap and Bapat (2010), Vazhacharickal *et al.* (2015) and Banergee *et al.* (2015).The fiber content of jackfruit seed flour was 2.55, 2.36 reported by Shrivastava and David (2015) and Tulyanthan *et al*. (2002).

5. Ash (%)

Table 6(f) shows that the ash content of fresh Jackfruit seed and Jackfruit seed flour. Ash content for fresh Jackfruit seed was 1.25±0.221%. The ash content varied for jackfruit seed flour was observed in the range of 1.12 – 2.10 %. The average ash content was 2.10±0.100, 1.15±0.23 and 1.1±0.067 at 50 °C, 60 °C, and 70 °C. Highest ash content was observed in 50 °C of jackfruit seed flour. The ash content decrease with the increase in temperature from 50 °C to 70 °C. The decrease in ash content was significant at p≤0.05. The ash content of fresh jackfruit seed reported in the literature was o.15% by Gupta *et al.* (2011) Similarly Noor *et al.* (2014) and Rajarajeshwari and Jamuna (1999) reported the ash content of jackfruit seed flour was 1.53 – 2.66, Khan *et al.* (2016) reported 1.25 per cent ash in jackfruit seed flour.

6. Carbohydrates (%)

Table 6 (e) shows that the carbohydrate content of fresh jackfruit seed and Jackfruit seed flour. Carbohydrate content for Jackfruit seed was 33.61±0.226 and carbohydrate content varied for jackfruit seed flour ranged was 75.4 – 81.02 %. The average carbohydrates content was 75.04±0.496, 78.25±0.721 and 81.07±0.933 at 50°, 60° and 70 °C respectively. Highest carbohydrate content observed at 70 °C of jackfruit seed flour. The carbohydrates content increasing with increase in temperature from 50 °C to 70 °C. The increase in carbohydrates was significant at p≤0.05. The carbohydrate content of fresh jackfruit seed reported in the literature was 25.8%, 38.4% by Jagtap and Bapat (2010), Vazhacharickal *et al.* (2015) and Banergee *et al.* (2015). The carbohydrates from the fresh jackfruit seed flour was 76.1%, 81.64 % reported by Kumar *et al.* (1988), Tulyanthan *et al*.(2002).

7. Water absorption capacity (g/ml)

Table 6 (h) shows that the Water absorption capacity of jackfruit seed flour. Water absorption capacity of jackfruit seed flour ranged was 2.10 – 2.50 g/ml and average water absorption capacity of jackfruit seed flour was 2.19±0.035, 2.36±0.059, 2.56±0.047 g/ml at 50 °C, 60 °C and 70 °C drying temperature. The highest water absorption capacity was observed at 70 °C drying temperature and lowest water absorption capacity was observed at 50 °C drying temperature. The water absorption capacity increases with increases with increase in temperature from 50 °C to 70 °C. The water absorption capacity was significant at p≤0.05. Odoemelam (2005) reported the water absorption capacity of jackfruit seed flour was 2.3g/ml, Rajarajeshwari and Jamuna (1999) and Tulyanthan *et al*. (2002) reported the water absorption capacity for Jackfruit seed flour was 2.1g/ml, and 2.05g/ml respectively.

8. Oil absorption capacity (g/ml)

Table 6(i) shows that the oil absorption capacity of jackfruit seed flour. The oil absorption capacity was in the range of 1.7- 2.3g/ml and average was 1.717±0.543, 2.140 ± 0.053, 2.38 ± 0.042 g/ml at 50 °C, 60 °C and 70 °C drying air temperature. The oil absorption capacity was highest at 70 °C and lowest at 50 °C. The oil absorption capacity was significant at p≤0.05. Odoemelam (2005) reported the 2.8 g/ml. oil absorption capacity of jackfruit seed flour. Rajarajeshwari and Jamuna (1999) reported the oil absorption capacity for jackfruit seed flour which was 1.8 g/ml.

9. Bulk density (g/ml)

Table 6 (f)shows that the bulk density for Jackfruit seed flour. Bulk density varied for jackfruit seed flour was in the range of 0.71 to 0.847 g/cc, 0.75 to 0.807g/cc and 0.614 to 0.738g/cc for 50 °C, 60 °C and 70 °C respectively. Highest bulk density observed at 50 °C of Jackfruit seed flour. Odoemelam (2005) reported the 0.6 g/cc value of jackfruit seed flour.

10. Colour

Table 6(g) shows the colour for the fresh jackfruit seed and Jackfruit seed flour dried at 50, 60 and 70°C. *L*,*a* and *b* value for fresh Jackfruit seed flour colour values for fresh seed was 129.04, 3.95, 26.63. The *L* value for 95.48 – 107.9. *L* value for colour for jackfruit seed flour was at 50 °C,60 °C,70 °C and average was 95.480 ± 0.017, 99.720 ± 0.010, 107.907 ± 0.038

respectively. The L values increases with drying air temperature from 50 °C to 70 °C. The drying air temperature had significant influence of *L* value of colour on jackfruit seed flour at p≤0.05. a value for Jackfruit seed flour 50 °C, 60 °C and 70 °C was in the range of 3.99 to 5.11 and decreases with increase in temperature from 50 °C to 70 °C and average a value was 5.11±0.012, 5.43±0.025, 3.99±0.010 at 50 °C, 60 °C and 70 °C respectively. The a value had significant influence of a value of colour on jackfruit seed flour at p≤0.05. The b value for Jackfruit seed flour at 50 °C, 60 °C and 70 °C was in the range of 18.71 – 22.52. 18.64 to 18.86, 24.81 to 24.84 and 22.51 to 22.54 and average was 18.713±0.127, 26.153±2.327and 22.527±0.015 at 50˚C, 60˚C and 70˚C respectively. The b value had significant influence of a value of colour on jackfruit seed flour at p≤0.05. Mukprasirt *et al.* (2004) reported the colour values *L*,*a* and *b* of Jackfruit seed flour was 89.49, 1.19, 11.31 respectively.

CONCLUSION

Air drying characteristics of Jackfruit seeds and the Physico-chemical and functional characteristics have been investigated. The Jackfruit seeds were dried from average initial moisture content of 124.41% (db) to 4.048% (db) at 50 °C; 123.22% (db) to 3.267% (db) at 60 °C; 125.480 to 3.303% (db) at 70 °C. It took around 38, 27, and 19 hrs. time to dry Jackfruit seeds, dried in convective hot air dryer, at 50, 60 and 70 °C temperature respectively. The effective diffusivity values greatly increased with increasing drying air temperature, i.e. 2.174×10^{-8}, 3.565×10^{-8}, and 6.26×10^{-8} at 50, 60, and 70 °C respectively. The activation energy for moisture diffusion was found to be 46.646 kJ/mol. The Henderson and Pabis model was well fitted to the drying data at 50, 60, 70 °C respectively. The drying of Jackfruit seed occurred in the falling rate period. The jackfruit seed flour obtained at 50 °C had better physico-chemical and functional properties than the samples obtained at other different temperatures selected for the study. Jackfruit seed flour at 50ºC contains, moisture 6.41 %, protein 11.6 %, and fat 1.66 %, fibre 2.83 % carbohydrate 75.4 %, ash 2.10 %. The flour had average of water absorption capacity at 50 °C (2.1ml/ g), oil absorption capacity (1.7ml/g).

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