International Journal of Food and Fermentation Technology
Citation: *Int. J. Food Ferment. Technol.*, **14**(02): 495-512, December 2024
DOI: 10.30954/2277-9396.02.2024.4

Research Paper

Thin Layer Drying Characteristics of Jackfruit Seeds and its Quality Evaluation

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Paper No.: 299 **Received:** 01-09-2024 **Revised:** 05-11-2024 **Accepted:** 28-11-2024

ABSTRACT

Thin layer drying characteristics of two types of jackfruit seeds i.e. firm flesh (*Kapa*) and soft flesh (*Barka*) were investigated as a function of temperature. Three mathematical models (Newton model, Page model and Henderson and Pabis model) are fitted to the experimental data for describing the thin layer drying behaviour of firm flesh (*Kapa*) and soft flesh (*Barka*) types of jackfruit seed were investigated. The experiments of convective hot air drying were carried out at 60, 90 and 120^0 C drying air temperatures for both firm flesh (*Kapa*) and soft flesh (*Barka*) type jackfruit seeds. Out of three models fitted Henderson and Pabis model was found to be most suitable to describe drying behaviour of firm flesh (*Kapa*) and soft flesh (*Barka*) type of jackfruit seed at 60, 90 and 120^0 C air temperature. Irrespective of the temperature the drying rate was characterized in falling rate period. The main factor controlling the drying rate was temperature. The soft flesh (*Barka*) jackfruit seed was dried from an initial moisture content of 130.15 % (db) to 10.66 % (db), 135.21 % to 10.05 % and 135.21 % to 10.14 % (db) at temperature 60, 90 and 120^0 C respectively. It took around 23, 17 and 3.7 hours to complete drying. *Kapa* (firm flesh) seed was dried from an initial moisture content of 101.81 % (db) to 9.006 % (db), 109.248 % to 9.225 % and 100.44 % to 10.30 % (db) at temperature 60, 90 and 120^0 C respectively. It took around 21, 16 and 3.7 hours to complete drying. Effect of drying air temperature on nutritional properties like, protein, fat, fiber and carbohydrates and functional properties like, water absorption capacity, oil absorption capacity, bulk density, flour dispersibility and foaming capacity were also determined and discussed.

Keywords: Jackfruit, drying, temperature, moisture, water absorption capacity, oil absorption capacity

Drying is one of the oldest and most widely used methods of food preservation. It is an important unit operation in the food processing industry. The basic objective in drying agricultural products is the removal of water in the solid up to a certain level at which microbial spoilage, deterioration and chemical reactions are greatly minimized (Ojediran and Raji, 2010). Longer shelf life, product diversity and substantial volume reduction are the reasons for popularity of dried fruits and vegetables and this could be expanded with improvements could increase the current degree of acceptance of dehydrated food market

Jackfruit (*Artocarpus heterophyllus Lam.)* is one of the evergreen trees of family *moraceae* in tropical areas and widely grown in Asia including India. The ripe

How to cite this article: Deshmukh, P.S. and Swami, S.B. (2024). Thin Layer Drying Characteristics of Jackfruit Seeds and its Quality Evaluation. *Int. J. Food Ferment. Technol.*, **14**(02): 495-512.

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

fruit contains flavorful yellow sweet bulbs and seeds. The seed is 2-3 cm in long and 1-2 cm in diameter. Up to 5000 seeds can be found in a single fruit (Menka *et al.* 2011). Seeds make-up around 10 to 15% of the total fruit weight and have high carbohydrate and protein contents (Tulyathan *et al.* 2002). Jackfruit occurs naturally in two textural forms; soft flesh (*Barka*) with soft and pulpy perianth while firm flesh (*Kapa*) with firm perianth when ripe (Odoemelam, 2005). Fig. 1 (a) shows the firm flesh (*Kapa*) jackfruit seeds and Fig. 1 (b) shows the soft flesh (*Barka)* jackfruit seed. The nutritional content of jackfruit seed is moisture content 61.8%, protein content (11.85 %), fibre content (3.19 %) and carbohydrate content is (26.20 %). The calorific value is 382.79 kcal/100g. The ash and fat contents (dry matter basis) is 0.15 % and 1.006 % respectively (Gupta *et al.* 2011). The Jackfruit seed flour contains an appreciable value of calcium (3087 mg/kg), Iron (130.74 mg/kg), potassium (14781 mg/kg), sodium (60.66 mg/kg), copper (10.45 mg/kg) and manganese (1.12 mg/kg). The jackfruit seed flour contains high water absorption capacity (25 %), fat absorption capacity (17.0 %) and bulk density (0.80 g/cm^3) is recorded (Ocloo *et al.* 2010). As the seeds are recalcitrant, they germinate immediately after maturity. Therefore, fresh seeds cannot be kept for long time. As a result, large amounts of the total seed remain unused. If these seeds are dried to safe storable moisture content, these can be preserved for longer duration which can be utillised by converting into flour. However, seed flour can be an alternative product to be used in some food stuffs such as white bread, cake, extrudate product and seed flour can also used as thickening and stabilizing agent. As jackfruit is highly seasonal and seeds have shorter shelf life, hence go waste during the seasonal glut. So, the seed flour can be an alternative intermediatory product, which can be stored and utilized both for value addition and to blend with other grain flours without affecting the functional and sensory profile of the final product. The jackfruit seed flour may also be blended with wheat flour to explore the potential of low cost flour from jackfruit seed as an alternative raw material for bakery and confectionary products.

Various researchers have reported the drying characteristics and various models fitted to the drying that are reported for drying cocoa, pumpkin, hazelnuts, pistachio nuts, soybean etc. (Hii *et al*. 2009; Sacilik, 2007; Ozedemir and Devres, 1999; Khazaei and Tavakolipour, 2011; Rafiee *et al*. 2008). No report are available so far for drying of firm flesh (Kapa) and soft flesh (Barka) type of jackfruit seeds by convective hot air drying.

Fig. 1 (a): Firm flesh (*Kapa*) jackfruit seed

Fig. 1 (b): Soft flesh (*Barka*) jackfruit seed

Various researchers have reported the nutritional and functional properties of flour that are reported for breadfruit, chick pea, mangrove seed, jackfruit seed flour, soybean etc. (Okorie, 2010; Sacilik, 2007; Daur *et al.* 1999; Seena *et al.* 2011; Ocloo *et al*. 2010). No report are available so far for nutritional and functional properties of firm flesh (Kapa) and soft flesh (Barka) type of jackfruit seeds by convective hot air drying.

Mathematical modeling of drying curves and formulation:

A few selected thin layer drying models, which might be adequate to describe thin-layer drying data for the firm flesh (*Kapa*) and soft flesh (*Barka*) types of jackfruit seeds are reviewed below.

1. Lewis model

Lewis (1921) described that the moisture transfer from the foods and agricultural materials can be seen as analogous to the flow of heat from a body immersed in cool fluid. This model assumes negligible internal resistance, which means no resistance to moisture movement from within the material to the surface of the material. By comparing this phenomenon with Newton's law of cooling, the drying rate is proportional to the difference in moisture content between the material being dried and equilibrium moisture content at the drying air condition as given in equation (1),

$$MR = \frac{M - M_e}{M_0 - M_e} = \exp(-kt) \qquad \ldots(1)$$

Where, MR = Dimensionless moisture ratio,

M = Moisture content at time t (% db),

M_0 = Initial moisture content (% db),

M_e = Equilibrium moisture content (% db),

k = Drying constant (min/h)

t = time (min)

This model is commonly used by researchers in describing the thin-layer drying characteristics of agricultural products i.e. hazelnuts, pumpkin seed, pistachio nuts, cocoa, millet etc. Ozdemir and Devres, 1999; Sacilik, 2007; Kashaninejad *et al*. 2007; Hii *et al.* 2009; Ojediran and Raji, 2010.

2. Page model

Page (1949) suggested a two constant empirical modification of the exponential model to correct for its shortcomings. This model is commonly used to describe drying of many foods and agricultural products such as, hazelnuts, millet, pumpkin seed, pistachio nuts, cocoa, millet etc. Ozdemir and Devres, 1999; Ojediran and Raji, 2010; Sacilik, 2007; Kashaninejad *et al*. 2007; Hii *et al.* 2009; Ojediran and Raji, 2010.

This model can be expressed as equation (2),

$$MR = \frac{M - M_e}{M_0 - M_e} = \exp(-kt^n) \qquad \ldots(2)$$

Where, MR = Dimensionless moisture ratio,

M = Moisture content at time t (% db),

M_0 = Initial moisture content (% db),

M_e = Equilibrium moisture content (% db),

k = Drying constant (min/h),

t = time (min),

n = number of observation

Henderson and Pabis model

This model has been used to model thin-layer drying characteristics of various agricultural products. Model has been used by researchers in modeling the drying characteristics of food and agricultural products, hazelnuts, black tea, millet, pumpkin seed, pistachio nuts, cocoa etc. Ozdemir and Devres, 1999; Panchariya *et al*. 2002; Ojediran and Raji, 2010; Sacilik, 2007; Kashaninejad *et al*. 2007; Hii *et al.* 2009. The simplest approximation form when only one term of the infinite series is used. Model can be expressed as equation (3),

$$MR = \frac{M - M_e}{M_0 - M_e} = a\exp(-kt)^n \qquad \ldots(3)$$

Where, MR = Dimensionless moisture ratio,

M = Moisture content at time t (% db),

M_0 = Initial moisture content (% db),

M_e = Equilibrium moisture content (% db),

k = Drying constant (min/h),

t = time (min),

n = number of observation,

a = coefficients in thin layer models.

Thus, the objective of this study was to find out drying behaviour and suitable model to investigate the effect of temperature on the model coefficients which can describe the drying characteristics of two types jackfruit seeds i. e. firm flesh (*Kapa)* and soft flesh (*Barka*). This study is also useful to calculate effective diffusivity, activation of energy and to find the best kinetic model for thin layer drying of two types of jackfruit seeds. It is also useful to determine effect of drying air temperature on nutritional and functional properties of jackfruit seed flour.

MATERIALS AND METHODS

The firm flesh *(Kapa*) and soft flesh (*Barka)* types of jackfruit for experimentation was procured from the university farm (CES, Wakwali), Dr. Balasaheb Sawant Konkan Krishi Vidyapeeth, Dapoli. Jackfruits are available in two types namely- firm flesh (*Kapa*) and soft flesh (*Barka*) as shown in Fig. 1(a) and 1(b). Both types were collected at its maturity stage and kept at room temperature for 2-3 days for ripening. Fully ripe jackfruits of two types were cut with power operated jackfruit cutter developed in NAIP - Kokum, Karonda Jamun and Jackfruit laboratory; the seeds and bulbs were removed from the perianths and separated manually. The fruit outer layer was separated manually and the bulbs and seeds were separated. The seeds were washed with water to remove any residual pulp adhered with it. The surface moisture of the seeds were removed with the help of blotting paper. Two types of seeds were selected i.e. firm flesh (*Kapa)* and soft flesh (*Barka*).

Initial moisture content of the jackfruit seed was calculated by using hot air as per AOAC, 2010.

$$\text{Moisture Content (db)\%} = \frac{W_1 - W_2}{W_2} \times 100 \qquad \ldots(4)$$

Where, W_1 = weight of sample before drying, *g*

W_2 = weight of bone dried sample, *g*

Experimental setup

Drying of jackfruit seed, firm flesh (*Kapa*) and soft flesh (*Barka)* were performed in the tray dryer at the Department of APE, CAET, Dapoli. The drying was carried out in a tray dryer (Make: M/S Rotex Industries, Pune) having capacity 60 kg. There were 24 no. of trays inside the tray dryer. The size of the tray was 54 cm× 50 cm × 2 cm. The temperature of the drying was kept as 60, 90 and 120^0C. The jackfruit seed firm flesh (*Kapa*) and soft flesh (*Barka*) were dried in a thin layer drying. Jackfruit seed of firm flesh (*Kapa*) type loaded in the dryer when the dryer attain 60^0 C set point temperature. Air velocity was fixed at 2 m/s. There were two heaters of 1.5 kW having total power 3 kW. The weight loss during drying was measured by three number of perforated trays placed at three different locations in tray dryer i.e. top, middle and lower side of the dryer. The weight loss was recorded by an electronic balance (Make: M/S Contech Instruments, Navi Mumbai; Model: CT-3K1) with an accuracy of 0.001 mg. The weight loss of the seeds recorded at 20 min interval upto 4 hours and then after at 1 h interval during progression of drying till the constant weight has achieved.

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 drying of firm flesh (*Kapa*) and soft flesh *(Barka)* types of jackfruit seed. Moisture ratio versus drying time (min) was also determined from the experimental data of firm flesh *(Kapa)* and soft flesh (*Barka)* type jackfruit seeds. Various mathematical models listed in equation (1) - (3) were fitted to the experimental data on moisture ratio versus drying time (minutes) of jackfruit seeds for firm flesh (*Kapa*) and soft flesh (*Barka)* with tray drying.

Non linear regression analysis was performed to the experimental data of both type jackfruit seed firm flesh (*Kapa*) and soft flesh (*Barka*) by using SAS 6.0 at 60, 90 and 120^0 C. The higher value of correlation coefficient (*r*) and lower value of *RMSE* (Root Mean Square Error) indicated that the model is best fitted to the experimental data (Ozdemir and Devres, 1999).

These parameters were calculated by using equations.

$$RMSE = \left[\frac{1}{N}\sum_{i=1}^{n}\left(MR_{\exp} - MR_{pre}\right)^2\right]^{\frac{1}{2}} \quad \ldots(5)$$

Where, MR_{exp} = experimental moisture ratio

MR_{pre}= predicted moisture.

N and *n* are the number of observations and the number of constants (Panchariya *et al*. 2002; Jittant, 2011).

Calculation of effective diffusivity and activation of energy

As for drying of the agricultural products in falling rate period, the liquid diffusion controls the process. Fick's second law can be used to describe the drying process. General series solutions of Fick's second law in spherical co-ordinates on jackfruit seed is assumed to resemble on spherical with diameter 57.2 and 58.2 mm for firm flesh (*Kapa*) and soft flesh (*Barka*) seeds. Effective diffusivity of firm flesh *(Kapa*) and soft flesh (*Barka)* type of jackfruit seeds were calculated by using Fick's Second law of diffusion (Doymaz and Pala, 2003) as given in equation (6).

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

Where, R^2 = equivalent radius of the jackfruit seed to be dried, *m* (for Kapa, *R* = 28.6 and for Barka, *R* = 29.1 mm)

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 diffusivities could be determined using the method of slopes as discussed by Panchariya *et al*. 2002; Kashaninejad *et al*. 2005; Radhika *et al*. 2011; (Ojediran and Raji, 2010). Effective diffusivities can be determined by plotting experimental drying data in terms of 'ln (MR)' versus 'time'.

$$1n\left(MR\right) = \frac{-6 \times t \times D_{eff}}{R^2} \quad \ldots(7)$$

The effective diffusivity can be determined from the slope of equation (9) (Sacilik, 2007).

$$\text{Effective diffusivity } (D_{eff}) = \frac{R^2 K}{\pi^2} \quad \ldots(8)$$

Effect of temperature on effective diffusivity is generally described using Arrhenius — type relationship to obtain better agreement of the predicted curve with experimental data. (Ozdemir and Devres, 1999) reasoned that diffusivity varies more with temperature than moisture content;

$$D_{eff} = D_0 \exp\left(\frac{E_\alpha}{RT_\alpha}\right) \quad \ldots(9)$$

Where, D_0 = diffusivity constant or Arrhenius pre-exponential factor (m^2/s),

E_a= activation energy (KJ/mol),

R = universal gas constant (KJ/ mol K).

A plot of logarithm of D_{eff} on function of reciprocal of the absolute temperature (T_a) gives the energy of activation as a slope and constant D_0 as the intercept. (Ozdemir and Devres, 1999); Kashaninnejad et al. 2007); (Panchariya *et al.* 2002); (Sacilik, 2007); (Tavakolipour, 2011) for hazelnuts, pistachio nuts, black tea).

Flour preparation

The dried seed of firm flesh (*Kapa*) and soft flesh (*Barka)* for varied temperature i.e. 60, 90 and 120^0 C in convective hot air tray dryer up to constant weight were taken out from the dryer and allowed to cool at ambient temperature and milled using pulverizer

(Make: M/S Sagar Engineering works, Kudal) were finally milled using pulveriser to make flour.

Nutritional and functional properties of Jackfruit seed flour

All nutritional and functional properties were determined at all three temperatures (60, 90 and 120^0 C) for both firm flesh (*Kapa*) and soft flesh (*Barka*) type jackfruit seed flour. Three replications of each test were carried out at each temperature for both types of jackfruit seed flour i.e. firm flesh (*Kapa*) and soft flesh (*Barka*) at 60, 90 and 120^0 C.

Nutritional analysis of flour

Protein, fat, crude fiber and moisture content were determined by using standard procedures (Ranganna, 1986) at all three 60, 90 and 120^0 C temperature, for firm flesh (*Kapa*) and soft flesh (*Barka*) jackfruit seed flour. Carbohydrate content was calculated from the protein, fat, fibre, ash and moisture content substraction method. Nutritional analysis was performed in the laboratories of the Department of Agricultural Chemistry and Soil Science, College of Agriculture, Dr. Balasaheb Sawant Konkan Krishi Vidyapeeth, Dapoli.Dapoli. The other experiment was performed at NAIP laboratory on A Value chain for Kokum, Karonda, Jamun and Jackfruit, Department of APE, CAET, Dr. Balasaheb Sawant Konkan Krishi Vidyapeeth, Dapoli. Three replications of each test were carried out at each temperature for both types of jackfruit seed flour i.e. firm flesh (*Kapa*) and soft flesh (*Barka*). The methods are as given below:

Functional properties of flour

Water absorption capacity, oil absorption capacity, bulk density, flour dispersibility, foaming capacity and foam stability for jackfruit seed flour of various treatment of drying i. e. 60, 90 and 1200 C for firm flesh (*Kapa*) soft flesh (*Barka*) was determined by following methods.

1. Water absorption capacity (ml/g)

Water absorption capacity of firm flesh (*Kapa*) and soft flesh (*Barka*) type jackfruit seed flour were determined using methods described by Odoemelam (2005). One gram jackfruit seed flour sample was weighed into 25 ml graduated conical tubes of centrifuge and about 10 ml of water added to it. The suspensions were allowed to stand at room temperature (30 ± 2 °C) for 1 h. The suspension was centrifuged at 2000 rpm for 30 minutes. The volume of water on the sediment was measured and the water absorbed expressed ml of water absorbed by 1 g of flour. Three replications were carried out for both types of jackfruit seed flour i.e. firm flesh (*Kapa)* and soft flesh (*Barka*) at 60, 90 and 120^0 C.

2. Oil absorption capacity (ml/g)

Oil absorption capacity of firm flesh (*Kapa*) and soft flesh (*Barka*) type jackfruit seed flour were determined using methods described by Odoemelam (2005). One gram jackfruit seed flour sample was weighed into 25 ml graduated conical tubes of centrifuge and about 10 ml of oil added to it. The suspensions were allowed to stand at room temperature (30 ± 2 °C) for 1 h. The suspension was centrifuged at 2000 rpm for 30 minutes. The volume of oil on the sediment was measured and the water absorbed expressed ml of oil absorbed by 1 g of flour. Three replications were carried out for both types of jackfruit seed flour i.e. firm flesh (*Kapa)* and soft flesh (*Barka*) at 60, 90 and 120^0 C.

3. Bulk density (g/cc)

Bulk density of firm flesh (*Kapa*) and soft flesh (*Barka)* type jackfruit seed flour were determined by the method of Ocloo *et al.* (2010). A graduated measuring cylinder weighed and flour sample was filled upto 5 ml by constant tapping until there was no further change in volume. The cylinder and flour upto 5 ml were weighed and the difference in weight was determined. The bulk density was computed as grams per milliliter of the sample. Three replications were carried out. Similar procedures were performed firm flesh (Kapa) and soft flesh (Barka) seed flour at 60, 90 and 120^0 C.

4. Flour dispersibility (%)

Dispersibility of firm flesh (*Kapa*) and soft flesh (*Barka*) type of jackfruit seed flour were measured by the method of Airani (2007). 10 grams of jackfruit seed flour sample was taken in 100 ml measuring cylinder. Distilled water added to the volume of 100 ml, stirred vigorously and allowed to settle for three hours. The volume of settled particles was subtracted from 100 and the difference was reported as percentage dispersibility. Similar procedure was reported for firm flesh *(Kapa)* and soft flesh *(Barka)* seed flour at 60, 90 and 120^0 C.

5. Foam capacity (g/ml)

Foam capacity of firm flesh (*Kapa*) and soft flesh (*Barka*) type of jackfruit seed flour were determined by the method of Odoemelam (2005). The jackfruit seed flour (2 g) was taken in a beaker and 100 ml water was added to it and mixture of water and sample were stirred at room temperature for 5 minutes using a magnetic stirrer. The contents along with foam were immediately poured into a 250 ml measuring cylinder. Volume of foam (ml) after pouring was expressed as the foam capacity in g/ml. Three replications were carried out for both types of jackfruit seed flour i. e. firm flesh (*Kapa*) and soft flesh (*Barka*) at 60, 90 and 120^0 C.

6. Foam stability (ml)

After experiment of foaming capacity the volume of the foam for the time period of 20-80 min was expressed as foam stability for the respective time periods. Three replications were carried out for both types of jackfruit seed flour i. e. firm flesh (*Kapa*) and soft flesh (*Barka*) at 60, 90 and 120^0 C.

RESULTS AND DISCUSSION

Drying characteristics

Fig. 2 shows moisture content (db) % w. r. t. time (min) of soft flesh *(Barka)* jackfruit seed by tray drying. The jackfruit seed were dried from an initial moisture content of 130.15 % (db) to 10.66 % (db), 135.21 % to 10.05 % and 135.21 % to 10.14 % (db) at temperature 60, 90 and 120^0 C respectively. It took around 23, 17 and 3.7 hours to complete drying. Fig. 3 shows moisture content (db) % w. r. t. time (min) of firm flesh (*Kapa*) jackfruit seed by tray drying. The jackfruit seed was dried from an initial moisture content of 101.81 % (db) to 9.0 % (db), 109.2 % to 9.2% and 100.4 % to 10.30 % (db) at temperature 60, 90 and 120^0 C respectively. It took around 21, 16 and 3.7 hours to complete drying.

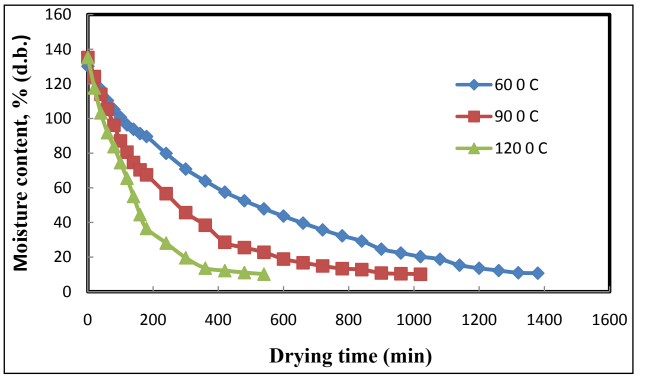

Fig. 2: Moisture content %(db) versus time (min) for drying of soft flesh (*Barka*) seed

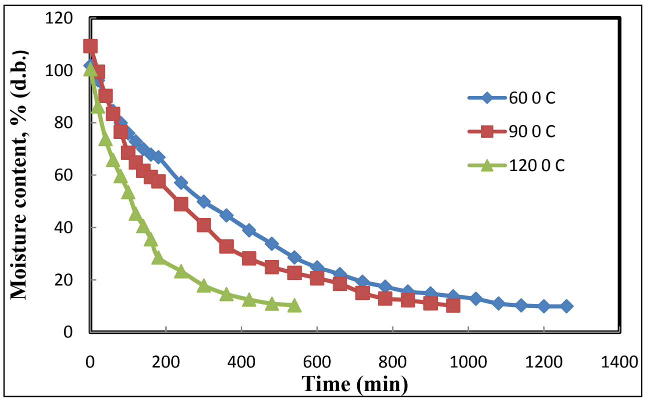

Fig. 3: Moisture content %(db) versus time (min) for drying of firm flesh (*Kapa*) seed

Fig. 4. Shows the drying rate (kg of water removed/ kg of dry matter/h) w. r. t. moisture content % (db) of soft flesh (*Barka*) seeds dried by tray drying at 60, 90 and 120^0 C temperature. The drying rate decreased from 0.33 to 0.0044, 0.54 to 0.0050 and 1.17 to 0.057 kg of water removed/kg of dry matter/h at temperature 60, 90 and 120^0 C. Fig. 5. Shows the drying rate (kg of water removed/kg of dry matter/h) w. r. t. moisture

content % (db) of firm flesh (*Kapa*) seeds dried by tray drying at 60, 90 and 120^{0} C. The drying rate decreased from 0.283 to 0.0002, 0.49 to 0.0148 and 0.95 to 0.0411 kg of water removed/kg of dry matter/h at temperature 60, 90 and 120^{0} C. In both type of jackfruit seeds i.e. firm flesh (*Kapa*) and soft flesh (*Barka*) drying occurred only in falling rate period.

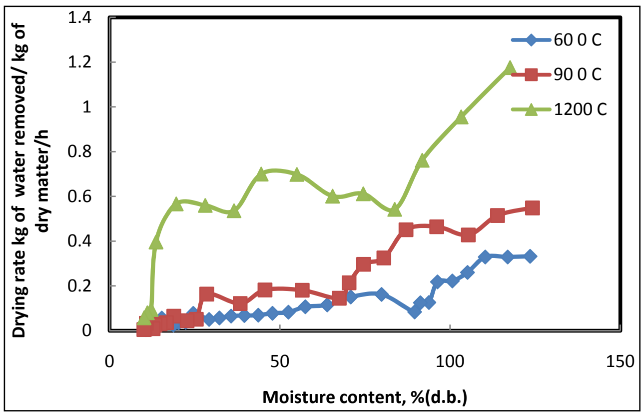

Fig. 4: Drying rate (kg of water removed/kg of dry matter/h) versus moisture content % (db) of soft flesh (*Barka*) jackfruit seed

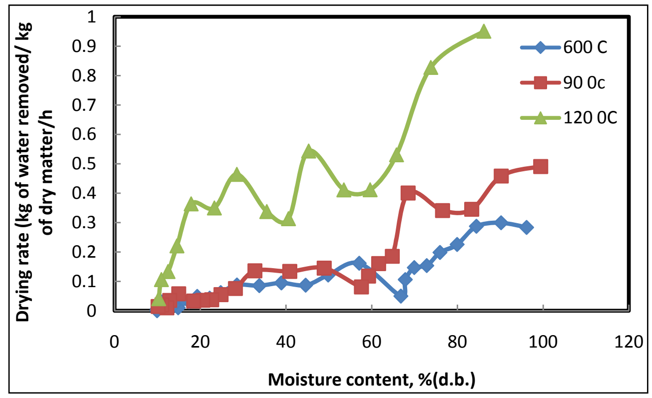

Fig. 5: Drying rate (kg of water removed/kg of dry matter/h) versus moisture content % (db) of firm flesh (*Kapa*) jackfruit seed

Modeling of Drying Curves

Table 2 shows various models i.e. Newton, Page, Henderson and Pabis model were fitted to the experimental data of firm flesh (*Kapa*) and soft flesh (*Barka*) type of jackfruit seeds i.e. Moisture ratio versus time (min). The Henderson and Pabis model fitted well among all the models tested for

Table 2: Model parameters and statistical results obtained for Newton, Page Henderson and Pabis for firm flesh (*Kapa*) jackfruit seed

Sl. No.	Drying Model	Temperature	Constants	r^2	RMSE
1	Newton	60^{0} C	2×10^{-3}	0.998	1×10^{-3}
		90^{0} C	4×10^{-3}	0.999	0.000
		120^{0} C	1.1×10^{-2}	0.982	5×10^{-3}
2	Page	60^{0} C	K= 2.84×10^{-3}		
			n= 9.68×10^{-1}	0.997	6.65 ×10^{-1}
		90^{0} C	K= 5.38×10^{-3}		
			n= 9.64×10^{-1}	0.993	1.62×10^{-4}
		120^{0} C	K= 2.05×10^{-3}		
			n=1.362	0.992	2.00×10^{-3}
3	Henderson and Pabis	60^{0} C	K= 2.26×10^{-3}		
			a=9.74×10^{-1}	0.997	5.85×10^{-4}
		90^{0} C	K= 4.37×10^{-3}		
			a= 9.86×10^{-1}	0.999	1.80 ×10^{-4}
		120^{0} C	K= 1.17×10^{-2}		
			a=1.05709029	0.983	4.39×10^{-4}

Table 3: Model parameters and statistical results obtained for Newton, Page Henderson and Pabis for soft flesh (*Barka*) jackfruit seed.

Sl. No.	Drying Model	Temperature	Constants	r^2	RMSE
1	Newton	60^0 C	3×10^{-3}	0.998	0.000
		90^0 C	4×10^{-3}	0.997	1×10^{-3}
		120^0 C	1.2×10^{-2}	0.989	3×10^{-3}
2	Page	60^0 C	K= 2.73×10^{-3}		
			n=1.01396107	0.998	4.58×10^{-4}
		90^0 C	K= 7.81×10^{-3}		
			n= 8.90×10^{-1}	0.998	3.65×10^{-4}
		120^0 C	K= 4.36×10^{-3}		
			n=1.21362785	0.993	1.68×10^{-3}
3	Henderson and Pabis	60^0 C	K= 2.93×10^{-3}		
			a= 9.90×10^{-1}	0.998	4.51×10^{-4}
		90^0 C	K= 4.04×10^{-3}		
			a= 9.55×10^{-1}	0.997	5.40×10^{-4}
		120^0 C	K= 1.20×10^{-2}		
			a=1.03183005	0.989	2.67×10^{-3}

the experimental data of firm flesh (*Kapa)* at $5.85 \times 10^{-4} \leq$ RMSE $\geq 4.39 \times 10^{-4}$; $0.999 \leq r^2 \geq 0.983$ and soft flesh (*Barka)* seeds at $4.51 \times 10^{-4} \leq$ RMSE $\geq 2.67 \times 10^{-3}$; $0.998 \leq r^2 \geq 0.989$ at 60, 90 and 120^0 C. a and n are the characteristics constants, which are temperature dependant.

Calculation of Effective diffusivity and activation of energy

Fig (6) and (7) shows graph of Ln (MR) versus time, min for firm flesh (*Kapa*) and soft flesh (*Barka*) seeds at varied temperature at 60, 90 and 120^0 C respectively. Linear equations obtained from the graph were compared with the standard equation i.e. $y= mx+c$. *"m"* value indicates the slope of line. Effective diffusivity (D_{eff}) at time (t) for firm flesh (*Kapa*) were 1.371×10^{-9}, 2.76×10^{-9} and 1.38×10^{-8} m^2/s and soft flesh (*Barka*) were 1.43×10^{-9}, 2.86×10^{-9} and 1.72×10^{-8} m^2/s calculated from equation (6) by convective hot air drying method at 60, 90 and 120^0 C (shown in table 4) .

The values of effective diffusivity *(D_{eff})* are reported to vary between 2.301×10^{-7} and 11.759×10^{-7} m^2/s over the temperature range 100- 160^0 C for hazelnuts (Ozedemir and Devres, 1999), 7.46×10^{-11} to 1.87×10^{-10} m^2/s for Cocoa at 60^0C to 80^0 C (Hii *et al.* 2009), 5.42×10^{-11} to 9.29×10^{-10} m^2/s for pistachio nuts (Kashaninejad *et al.* 2007), 7.061×10^{-10} to 2.105×10^{-9} m^2/s for pistachio nuts at 40 -70^0C (Tavakolipour, 2011), 8.53×10^{11} to 17.52×10^{11} at temperature 40-60^0C for pumpkin seed (Sacilik *et al*. 2007), 7.69×10^{-11} and 50.96×10^{-11} m^2/s for pumpkin seed at temperature 40 to 60^0 C (Jittanit, 2011).

Table 4: Effective diffusivity (m^2/s) at different temperature for jackfruit seed

		Effective diffusivity (m^2/s)		
Sl. No.	**Temperature**	**60^0 C**	**90^0 C**	**120^0 C**
1	Firm flesh (*Kapa*)	1.371×10^{-9}	2.76×10^{-9}	1.38×10^{-8}
2	Soft flesh (*Barka*)	1.43×10^{-9}	2.86×10^{-9}	1.72×10^{-8}

The results show a linear relationship between (log D_{eff}) and ($1/T_a$) as plotted in Fig (8) for firm flesh (*Kapa)* and Fig (9) for soft flesh (*Barka*) type of jackfruit seed. The diffusivity constant or pre- exponential factor of Arrhenius equation (D_0) and activation of energy (E_a) calculated from the linear regression are 4.3252 × 10^{-4} m^2/s and 35122.8 KJ/mol for firm flesh (*Kapa*) and 1.4985 × 10^{-3} m^2/s and 3864.44 KJ/mol for soft flesh (*Barka*) type of jackfruit seed. Equation (15) and (16) shows the effect of temperature on effective diffusivity of firm flesh (*Kapa*) and soft flesh (*Barka*) type of jackfruit seed.

$$D_{eff} = 1.495 \times 10^{-3} \left(-\frac{3864.44}{T_{\alpha}} \right) (Barka) \qquad \ldots(10)$$

$$D_{eff} = 4.325 \times 10^{-4} \left(-\frac{35122.8}{T_{\alpha}} \right) (Kapa) \qquad \ldots(11)$$

This result one in agreement with the, the values of activation of energy (E_a) and Arrhenius pre-exponential factor (D_0) are 4099.8KJ/mol and 0.014 m^2/s for hazelnuts at 100-160^0 C. 33.15 KJ/mol and 1.95×10^{-5} m^2/s for pumpkin seed at 40 - 60^0 C. 44.92 KJ/mol and 8.43×10^{-4} m^2/s for cocoa at 60 – 80^0 C. 15 KJ/mol and 8.393×10^{-8} m^2/s for pumpkin seeds at 60- 80^0 C respectively.

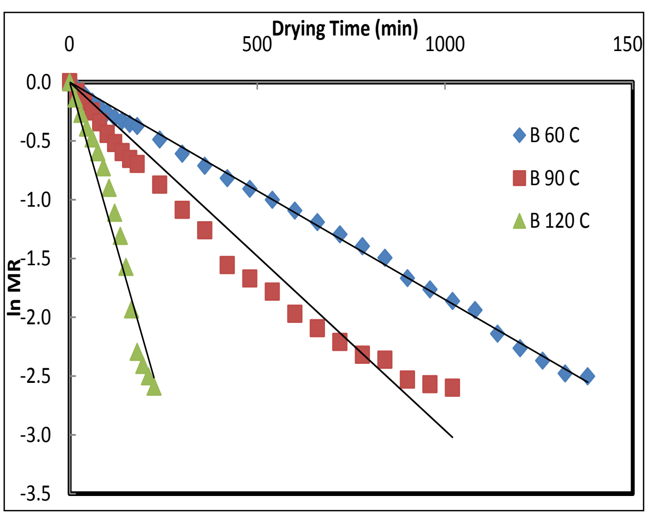

Fig. 6: Ln (MR) versus time, min for effective diffusivity of soft flesh (*Barka*) jackfruit seed

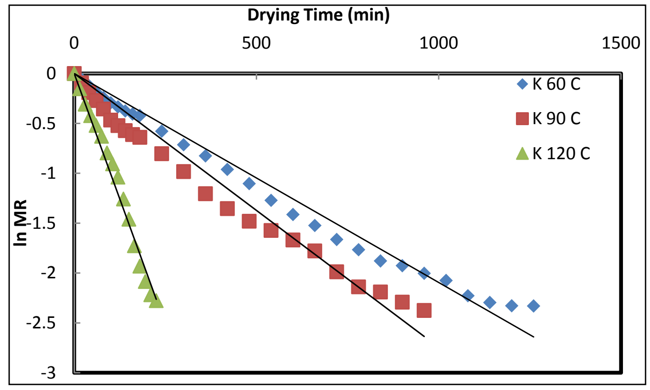

Fig. 7: Ln (MR) versus time, min for effective diffusivity of firm flesh (*Kapa*) jackfruit seed

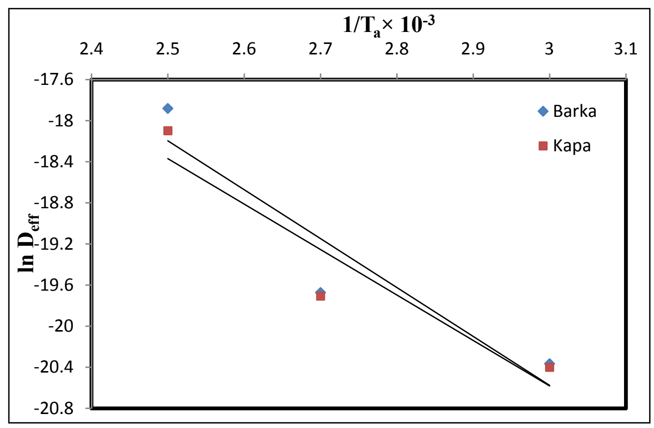

Fig. 8: Arrhenius- type relationship between effective diffusivity and temperature for soft flesh (Barka) and firm flesh (*Kapa*) jackfruit seed

Nutritional properties of flour

Table (5) and (6) shows the nutritional properties of firm flesh (*Kapa)* and soft flesh *(Barka)* type jackfruit seed flour.

1. Moisture content

Moisture content of jackfruit seed flour were decreases as drying temperature increases at 60^0 C flour shows greater moisture content than 90 and 120 ^{0}C for both firm flesh (*Kapa*) and soft flesh (*Barka*) types of jackfruit seed flour. Moisture content of firm flesh *(kapa)* samples were 11.29 ±0.008, 9.27 ± 0.024 and 8.28 ±0.032 and soft flesh *(Barka)* as 11.24 ±0.04, 9.20 ±0.08 and 8.36±0.14 % at 60, 90 and 120^0 C respectively. Table 7 (a) and 8 (a) shows the ANOVA

Table 5: Nutritional properties of soft flesh (*Barka*) jackfruit seed flour

Sl. No.	Properties	60^0 C	90^0 C	120^0 C
1	Moisture content (% wb)	11.24±0.04	9.20±0.08	8.36±0.14
2	Protein (%)	12.19±0.054	12.04±0.099	11.39±0.138
3	Fat (%)	1.52±0.065	1.26±0.024	1.14±0.0124
4	Fibre (%)	11.29±0.008	9.27±0.024	8.28±0.032
5	Carbohydrates (%)	69.09±0.69	70.90±0.37	72.36±0.43

Table 6: Nutritional properties of firm flesh (*Kapa*) jackfruit seed flour

Sl. No.	Properties	60^0 C	90^0 C	120^0 C
1	Moisture content (% wb)	11.29±0.008	9.27±0.024	8.28±0.032
2	Protein (%)	12.25±0.172	12±0.081	11.32±0.183
3	Fat (%)	1.64±0.027	1.29±0.011	1.22±0.216
4	Fiber (%)	2.35±0.029	2.45±0.032	2.96±0.0081
5	Carbohydrates (%)	68.32±0.188	70.26±0.224	71.95±0.118

for change in moisture content at varied temperature, at 60, 90 and 120^0 C for firm flesh (Kapa) and soft flesh (Barka) type of jackfruit seed flour. These decreases in moisture content with increase temperature were significant at $p \leq 0.01$ for both firm flesh (*Kapa)* and soft flesh (*Barka*) type of jackfruit seed flour. The increase in temperature with decrease in moisture content has been reported for mangrove flour, chickpea flour and Breadfruit seed flour. Seena *et al.* 2006; Daur et al. 2008 and Okorie, 2010 respectively.

2. Protein

Protein content of jackfruit seed flour were decreases as drying temperature increases at 60^0 C flour shows greater protein content than 90 and 120 ^{0} C for both firm flesh (*Kapa*) and soft flesh (*Barka*) types of jackfruit seed flour. Protein content of firm flesh *(kapa*) samples were 12.25 ±0.172, 12 ± 0.081 and 11.32 ±0.183 and soft flesh *(Barka*) as 12.19 ±0.054, 12.04 ±0.099 and 11.39 ±0.138 % at 60, 90 and 120^0 C respectively. Table 7 (b) and 8 (b) shows the ANOVA for change in protein at varied temperature, at 60, 90 and 120^0 C for firm flesh (Kapa) and soft flesh (Barka) type of jackfruit seed flour. These decreases in protein with increase temperature were significant at $p \leq 0.01$ for both firm flesh (*Kapa)* and soft flesh (*Barka*) type of jackfruit seed flour. The increase in temperature with decrease in protein has been reported for mangrove flour, Beni seed flour, chickpea flour and Breadfruit seed flour. Seena *et al.* 2006; Adegunwa *et al*. 2012; Daur *et al.* 2008 and Okorie, 2010 respectively.

3. Fat

Fat content of firm flesh (*Kapa*) and soft flesh *(Barka*) type of jackfruit seed flour decreases as temperature increases. The fat content of the flour samples varied from 1.64±0.027, 1.29 ± 0.011 and 1.22 ±0.216 % at 60, 90 and 120^0 C respectively for firm flesh (*Kapa*). Fat content of soft flesh (*Barka*) also shows similar trend as it decreases with increase in temperature 1.52±0.065, 1.26 ±0.024 and 1.14± 0.0124 at 60, 90 120^0 C respectively. Table 7 (c) and 8 (c) shows the ANOVA for change in fat content at varied temperature, at 60, 90 and 120^0 C for firm flesh (Kapa) and soft flesh (Barka) type of jackfruit seed flour. These decreases in fat with increase temperature were significant at $p \leq 0.01$ for both firm flesh (*Kapa)* and soft flesh (*Barka*) type of jackfruit seed flour. The increase in temperature with decrease in fat has been reported for Breadfruit seed flour, Moringa oleifera Seeds. Okorie, 2010; Mbah *et al*. 2012 respectively.

Table 7: ANOVA for the nutritional composition for the firm flesh (*Kapa*) seed flour

Source of Variation	SS	Df	MS	F	P-value	F critical
(a) Moisture						
Between Groups	35.96153	5	7.192307	2969.301	4.06E-18	5.064343
Within Groups	0.029067	12	0.002422			
Total	35.9906	17				
(b) Protein content						
Between Groups	19.04904	5	3.809809	171.828	9.84E-11	5.064343
Within Groups	0.266067	12	0.022172			
Total	19.31511	17				
(c) Fat content						
Between Groups	0.781626	5	0.156325	115.1822	1.03E-09	5.064343
Within Groups	0.016286	12	0.001357			
Total	0.797912	17				
(d) Fibre content						
Between Groups	1.923161	5	0.384632	67.80979	2.24E-08	5.064343
Within Groups	0.068067	12	0.005672			
Total	1.991228	17				
(e) Carbohydrate content						
Between Groups	28.21814	5	5.643628	183.6678	6.64E-11	5.064343
Within Groups	0.368728	12	0.030727			
Total	28.58687	17				

Table 8: ANOVA for the nutritional composition for the soft flesh (*Barka*) seed flour

Source of Variation	SS	Df	MS	F	P-value	F critical
(a) Moisture						
Between Groups	34.45209	5	6.890419	876.5197	6.06E-15	5.064343
Within Groups	0.094333	12	0.007861			
Total	34.54643	17				
(b) Protein content						
Between Groups	21.39176	5	4.278352	208.0236	3.18E-11	5.064343
Within Groups	0.2468	12	0.020567			
Total	21.63856	17				
(c) Fat content						
Between Groups	0.5316	5	0.10632	63.792	3.18E-08	5.064343
Within Groups	0.02	12	0.001667			
Total	0.5516	17				
(d) Fibre content						
Between Groups	1.733094	5	0.346619	10.24994	0.000524	5.064343
Within Groups	0.4058	12	0.033817			
Total	2.138894	17				
(e) Carbohydrate content						
Between Groups	23.67429	5	4.734859	9.169173	0.000872	5.064343
Within Groups	6.196667	12	0.516389			
Total	29.87096	17				

4. Fiber

Fiber content of jackfruit seed flour were increases as drying temperature increases. Fiber content of firm flesh (*kapa*) samples were 2.35 ± 0.008, 2.47 ±0.024 and 3.06 ± 0.032 % and soft flesh (*Barka)* as 2.37±0.029, 2.45 ±0.032 and 2.96± 0.0081 at 60, 90 and 120^0 C respectively. Table 7 (d) and 8 (d) shows the ANOVA for change in fiber at varied temperature, at 60, 90 and 120^0 C for firm flesh (Kapa) and soft flesh (Barka) type of jackfruit seed flour. These increase in fibre with increase temperature were significant at p≤0.01 for both firm flesh (*Kapa)* and soft flesh (*Barka*) type of jackfruit seed flour. The increase in temperature with increase in fiber has been reported for Moringa oleifera Seeds, Beni seed flour and Breadfruit seed flour. Mbah *et al*. 2012; Adegunwa *et al*. 2012 and Okorie, 2010 respectively.

5. Carbohydrate

Carbohydrate content of jackfruit seed flour were increases as drying temperature increases from 90 to 120^0 C for both firm flesh (*Kapa*) and soft flesh (*Barka*) types of jackfruit seed flour. Carbohydrate content of firm flesh (kapa) seed flour were 68.3±0.188, 70.8±0.224 and 72± 0.118 % for and soft flesh (*Barka*) as 69±0.69, 79.35±0.38 and 72.45± 0.43 % at 60, 90 and 120^0 C respectively. Table 7 (e) and 8 (e) shows the ANOVA for change in carbohydrate content at varied temperature, at 60, 90 and 120^0 C for firm flesh (Kapa) and soft flesh (Barka) type of jackfruit seed flour. This increase in carbohydrate with increase in temperature was significant at p≤0.01 for both firm flesh (*Kapa)* and soft flesh (*Barka*) type of jackfruit seed flour.

Functional properties of flour

Table (9) and (10) shows the functional properties of firm flesh (*Kapa*) and soft flesh (*Barka*) type jackfruit seed flour.

1. Water absorption capacity (ml/g)

The water absorption capacity of jackfruit seed flour increased as drying temperature increases from 60 to $120\ ^0$ C, in both firm flesh (*Kapa*) and soft flesh (*Barka*) types of jackfruit seed flour. The water absorption capacities of firm flesh (*kapa*) samples were

Table 9: Functional properties of firm flesh (*Kapa*) jackfruit seed flour

Sl. No.	Properties	60^0 C	90^0 C	120^0 C
1	Water absorption capacity (ml/g)	2.23±0.094	2.63±0.047	3.13±0.047
2	Oil absorption capacity (ml /g)	2.16±0.047	2.53±0.047	2.96±0.047
3	Bulk density(g/cc)	0.69±0.0038	0.58±0.0110	0.57±0.0140
4	Flour dispersibility (%)	39±0.81	40.6±0.94	41.33±0.94
5	Foaming capacity (g/ml)	7.2±0.081	6.16±0.12	5.86±0.20
6	Foam stability (ml)	1.7±0.01	1.36±0.0133	1.066±0.003

Table 10: Functional properties of soft flesh (*Barka*) jackfruit seed flour

Sl. No.	Properties	60^0 C	90^0 C	120^0 C
1	Water absorption capacity (ml/g)	2.1±0.12	2.5±0.047	3.1±0.04
2	Oil absorption capacity (ml /g)	2.06±0.047	2.53±0.047	2.86±0.047
3	Bulk density (g/cc)	0.66±0.0078	0.58±0.0052	0.56±0.019
4	Flour dispersibility (%)	37±1.414	39.66±0.471	41.66±0.471
5	Foaming capacity (g/ml)	7.16±0.047	6.46±0.20	5.93±0.094
6	Foam stability (ml)	1.76±0.0033	1.366±0.0233	1.033±0.003

2.23±0.094, 2.63± 0.047 and 3.13± 0.047 ml/g and soft flesh (*Barka*) as 2.13±0.12, 2.76±0.047 and 3.14 ±0.04 ml/g at 60, 90 and 120^0 C respectively. Table 11 (a) and 12 (a) shows the ANOVA for the water absorption capacity of jackfruit seed flour at varied temperature for both firm flesh (*Kapa)* and soft flesh *(Barka*) seed flour. These increase in water absorption capacity with respect to the temperature were significant at p≤0.01 for both firm flesh *(Kapa)* and for soft flesh (*Bark*a) type of jackfruit seed flour. Carbohydrates in the form of starch play an important role in water absorption. During heat processing the gelatinization of starch (carbohydrate) and Swelling of the fibre occurs which could also leads to increased water absorption capacity (Odoemelam, 2005). The increase in temperature with increase of water absorption capacity has been reported for flaxseed flour, Oze seed flour and Jackfruit seed flour. Hussain *et al.* 2008; Nwosu, 2010 and Odoemelam, 2005 respectively.

2. Oil absorption capacity (ml/g)

Oil absorption is an important property in food formulations because fat improves the flavor and mouth feel of food (Chowdhury *et al*. 2012). The oil absorption capacity of jackfruit seed flour increases with increase in temperature for both firm flesh (*Kapa*) and soft flesh (*Barka*) seeds. The oil absorption capacity of the flour samples varied from 2.16±0.047, 2.53 ±0.047 and 2.86 ±0.047 ml/g at 60, 90 and 120^0 C for firm flesh (*Kapa*) respectively (table 9 and 10). Oil absorption capacity of soft flesh (*Barka*) also shows same trend as, 2.06 ± 0.047, 2.53 ±0.047 and 2.86 ± 0.047 ml/g at 60, 90 120^0 C respectively. Table 11 (b) and 12 (b) shows the ANOVA for the oil absorption capacity of jackfruit seed flour at varied temperature for both firm flesh (*Kapa)* and soft flesh *(Barka*) seed flour. These increase in oil absorption capacity with respect to the temperature were significant at p≤0.01 for both firm flesh *(Kapa)* and for soft flesh (*Bark*a) type of jackfruit seed flour. The similar increase in temperature with increase of oil absorption capacity has been reported for pearl millet flour, pumpkin flour and Jackfruit seed flour. Sade *et al.* 2009; Fagbemi *et al*. 2005 and Odoemelam, 2005 respectively.

3. Bulk density (g/cc)

The bulk density of jackfruit seed flour decrease with increase in temperature for both the firm flesh *(Kapa*) and soft flesh (*Barka*) seed flour. Bulk density of the flour samples varied from 0.69± 0.0038, 0.581± 0.0110 and 0.578 ± 0.0140 g/cc at 60, 90 and 120^0 C respectively for firm flesh (*Kapa)* jackfruit seed flour. Soft flesh (*Barka)* type jackfruit seed flour bulk density varies 0.661 ± 0.0078, 0.588± 0.0052 and 0.565± 0.019 g/cc at 60, 90 and 120^0 C respectively. Table 11 (c) and 12 (c) shows the ANOVA for the bulk density of jackfruit seed flour at varied temperature for both firm flesh (*Kapa)* and soft flesh *(Barka*) seed flour. These decrease in bulk density with respect to the temperature were significant at p≤0.01 for both firm flesh *(Kapa)* and for soft flesh (*Bark*a) type of jackfruit seed flour. Low bulk density of flour are good physical attributes when determining transportation and storability since the products could be easily transported and distributed to required locations. The increase in temperature with decrease of bulk density has been reported for Jackfruit seed flour (Odoemelam, 2005).

4. Flour dispersibility (%)

Flour dispersibility of jackfruit seed flour at 60 to 120^0 C temperature increases in both firm flesh (*Kapa*) and soft flesh (*Barka*) seed flour. The flour dispersibility of firm flesh (*kapa*) type jackfruit seed flour were 39± 0.81, 40.6±0.94 and 41.33±0.94% and soft flesh (*Barka*) as 37±1.4142, 39.66± 0.471 and 41.66± 0.471 % at 60, 90 and 120^0 C respectively. Table 11 (d) and 12 (d) shows the ANOVA for the flour dispersibility of jackfruit seed flour at varied temperature for both firm flesh (*Kapa)* and soft flesh *(Barka*) seed flour. These increase in flour dispersibility with temperature were significant at p≤0.01 for both firm flesh (*Kapa)* and soft flesh (*Barka*) type of jackfruit seed flour. The increase in temperature with increase of flour dispersibility has been reported for pumpkin flour, Hamed *et al.* 2010.

5. Foaming capacity (g/ml)

Foaming capacity of jackfruit seed for firm flesh (*Kapa*) and soft flesh (*Barka*) decreases with increase

Table 11: ANOVA for functional properties of soft flesh (*Barka*) Jackfruit Seed Flour

Source of Variation	SS	Df	MS	F	P-value	F critical
(a) Water Absorption Capacity (ml/g)						
Between Groups	1.804444	5	0.360889	59.0545	4.94E-08	5.064343
Within Groups	0.073333	12	0.006111			
Total	1.877778	17				
(b) Oil Absorption Capacity (ml/g)						
Between Groups	1.245	5	0.249	37.35	6.56E-07	5.064343
Within Groups	0.08	12	0.006667			
Total	1.325	17				
(c) Flour Bulk Density(g/cc)						
Between Groups	0.129449	5	0.02589	150.2614	2.17E-10	5.064343
Within Groups	0.002068	12	0.000172			
Total	0.131516	17				
(d) Flour Dispersibility (%)						
Between Groups	87.16667	5	17.43333	13.64348	0.000134	5.064343
Within Groups	15.33333	12	1.277778			
Total	102.5	17				
(e) Foaming Capacity (g/ml)						
Between Groups	10.82444	5	2.164889	3.85821	0.025701	5.064343
Within Groups	6.733333	12	0.561111			
Total	17.55778	17				
(f) Foam stability (ml)						
Between Groups	1.029444	5	0.205889	20.58889	1.65E-05	5.064343
Within Groups	0.12	12	0.01			
Total	1.149444	17				

Table 11: ANOVA for functional properties of firm flesh (*Kapa*) Jackfruit Seed Flour

Source of Variation	SS	Df	MS	F	P-value	F critical
(a) Water Absorption Capacity (ml/g)						
Between Groups	2.131667	5	0.426333	29.51538	2.4E-06	5.064343
Within Groups	0.173333	12	0.014444			
Total	2.305	17				
(b) Oil Absorption Capacity (ml/g)						
Between Groups	1.137778	5	0.227556	68.26667	2.15E-08	5.064343
Within Groups	0.04	12	0.003333			
Total	1.177778	17				
(c) Flour Bulk Density(g/cc)						
Between Groups	0.112656	5	0.022531	181.902	7.03E-11	5.064343
Within Groups	0.001486	12	0.000124			
Total	0.114143	17				
(d) Flour Dispersibility (%)						
Between Groups	108.444	5	21.688	27.8857	3.27E-06	5.064343
Within Groups	9.33333	12	0.7777			
Total	117.777	17				
(e) Foaming Capacity (g/ml)						
Between Groups	3.151111	5	0.630222	25.78182	4.99E-06	5.064343
Within Groups	0.293333	12	0.024444			
Total	3.444444	17				
(f) Foam stability (ml)						
Between Groups	1.249444	5	0.249889	2.485083	0.091183	5.064343
Within Groups	1.206667	12	0.100556			
Total	2.456111	17				

in temperature from 60 to 120^0 C and these values are 7.2±0.081, 6.1± 0.12, 5.8± 0.20 and 7.1± 0.047, 6.4±0.20 and 5.9 ±0.094 at 60, 90 and 120^0 C respectively. As proteins are heat labile hence foam capacity reduced due to protein denaturation (Odoemelam, 2005). Table 11 (e) and 12 (e) shows the ANOVA for the foaming capacity of jackfruit seed flour at varied temperature for both firm flesh (*Kapa)* and soft flesh *(Barka*) seed flour. These decrease in foaming capacity with increasing temperature were significant for firm flesh *(Kapa*) and not significant for soft flesh (*Barka*) at p≤0.01 jackfruit seed flour (table 10 and 11). The increase in temperature with decrease of foaming capacity has been reported for Beniseed flour, pumpkin flour and Jackfruit seed flour. Adegunawa., 2012; Fagbemi *et al*. 2005 and Odoemelam, 2005 respectively.

6. Foam stability (ml)

Foam stability of jackfruit seed for firm flesh (*Kapa*) and soft flesh (*Barka*) decreases with increase in temperature from 60 to 120^0 C. Foam of low temperature jackfruit seed flour is more stable than high temperature. Foam stability after 80 minutes stabilization are, for firm flesh (*Kapa*) are 1.7±0.01, 1.36±0.0133 and 1.06±0.003 ml and for soft flesh (*Barka*) are 1.76±0.0033, 1.366±0.0023 and 1.033±0.003 ml at 60, 90 and 120^0 C respectively. Table 11 (f) and 12 (f) shows the ANOVA for the foam stability of jackfruit seed flour at varied temperature for both firm flesh (*Kapa)* and soft flesh *(Barka*) seed flour. These decreases in foam stability with increasing temperature were not significant for firm flesh *(Kapa*) and soft flesh (*Barka*) at p≤0.01. The increase in temperature with decrease of foam stability has been reported for Beniseed flour, flaxseed flour and Jackfruit seed flour. Adegunawa., 2012; Hussain *et al*. 2010 and Odoemelam, 2005 respectively.

NOMENCLATURE

MR	Moisture Ratio
a, *n* and *t*	Constant
T	Time, min
M	Moisture Content at time t, % db
M_e	Equilibrium Moisture Content, % db
M_0	Initial Moisture Content, % db
R	Correlation Coefficient
RMSE	Root Mean Square Error
D_{eff}	Effective diffusivities, m^2/s
R^2	Radius, m

CONCLUSION

1. Tray drying of firm flesh (*Kapa*) was dried from an initial moisture content of 130.1 % (db) to 10.6 % (db), 135.2 % to 10.0 % and 135.2 % to 10.14 % (db) at temperature 60, 90 and 120^0C respectively. It took around 23, 17 and 3.7 hours to complete drying.
2. In tray drying of soft flesh (*Kapa)* was dried from an initial moisture content of 101.81 % (db) to 9.0 % (db), 109.24 % to 9.2 % and 100.4 % to 10.30 % (db) at temperature 60, 90 and 120^0C respectively. It took around 21, 16 and 3.7 hours to complete drying.
3. Handerson and Pabis model found well fitted to experimental moisture ratio data with r^2= 0.997; *RMSE*= 5.85×10^{-4} and a = 9.74×10^{-1} at 60^0 C, r^2= 0.999; *RMSE*= 1.80×10^{-4} and *a* = 9.86×10^{-1} at 90^0 C and r^2= 0.983; *RMSE*= 4.39×10^{-4} and *a* = 1.0570 at 120^0 C for firm flesh (*Kapa*) type jackfruit seed drying by convective hot air method.
4. Handerson and Pabis model found well fitted to experimental moisture ratio data with r^2= 0.998; *RMSE*= 4.51×10^{-4} and a = 9.90×10^{-1} at 60^0 C, r^2= 0.997; *RMSE*= 5.40×10^{-4} and *a* = 9.55×10^{-1} at 90^0 C and r^2= 0.989; *RMSE*= 2.67×10^{-3} and *a* = 1.031 at 120^0 C for soft flesh (*Barka*) type jackfruit seed drying by convective hot air method.
5. Effective diffusivity (D_{eff}) at time (t) for firm flesh (*Kapa*) were 1.37 $\times10^{-9}$, 2.76×10^{-9} and 1.38 $\times10^{-8}$ m^2/s and soft flesh (*Barka*) were 1.43 $\times10^{-9}$, 2.86 $\times10^{-9}$ and 1.72 $\times10^{-8}$ m^2/s at 60, 90 and 120^0C.
6. The diffusivity constant (D_0) and activation of energy (E_a) calculated from the linear regression are 4.3252×10^{-4} m^2/s and 35122.8 KJ/mol for firm flesh (*Kapa*) and 1.4985×10^{-3} m^2/s and 3864.44 KJ/

mol for soft flesh (*Barka)* type of jackfruit seed.

7. The nutritional properties (protein, fat, fibre and carbohydrate content) and functional properties (water absorption capacity, oil absorption capacity, flour dispersibility, bulk density, foaming capacity and foam stability) of firm flesh (*Kapa*) and soft flesh (*Barka*) type of jackfruit seed changes with drying temperature.

REFERENCES

Adegunawa, M.O., Adebowale, A.A. and Solano, E.O. 2012. Effect of thermal processing on biochemical composition, antinutritional factors and functional properties of Beni seed (*Sesamum indicum*) flour. *American Journal of Biochemistry and Molecular Biology*, **2**(3): 175-182.

Airani, S. 2007. Nutritional quality and value addition to jackfruit seed flour. Master of home science thesis. University of Agricultural Sciences, Dharwad. November 2007, 17-19.

A.O.A.C. 2010. Official Methods of Analysis. 18th Edition. Association of Official Analytical Chemists.

Chowdhury, A., Bhattacharyya, A.K. and Chattopadhyay, P. 2012. Study on functional properties of raw and blended jackfruit seed flour for food application. *Indian Journal of Natural Products and Resources*, (3): 347-353.

Daur, I., Khan, I.Z. and Jahangir, M. 2008. Nutritional qualities of roasted and pressure cooked chickpea (*Cicer arientium L*) compared to raw seed. *Sarhad Journal of Agriculture*, **24**(1); 117- 122.

Doymaz, I. and Pala, M. 2003. The thin layer drying characteristics of corn. *Journal of food Engineering*, **60**: 125-130.

Fagbemi, T.M., Oshodi, A.A. and Ipinmoroti, K.O. 2005. Effect of processing on functional properties of full fat and defatted fluted pumpkin seed flours. *Journal of Food Technology*, **3**(3): 370-377.

Fasai, O.S. 2009. Proximate, antinutritional factors and functional properties of processed pearlmillet (*Pennisetum glaucum*). *Journal of food technology*, **7**(3): 92-97.

Goswami, C., Hossain, M.A., Moutuza, M.G. and Islam, R. 2010. Physicochemical parameters of jackfruit seed in different growing area. *International Journal of Biological Resources*, **2**(10): 01-05.

Hamed, S.Y., Nafisa, M., Hassan, E.I. and Hassan, A.B. 2008. *Pakistan Journal of Nutrition*, **7**(2): 330-334.

Hii, C.L., Law, C.L. and Cloke, M. 2009. Modeling using a new thin layer model and product quality of cocoa. *Journal of food Engineering*, **90**: 191-198.

Hussain, S., Anjum, F.M., Butt, M.S. and Sheikh, M.A. 2008. Chemical compositions and functional properties of flaxseed flour. *Sarhad Journal of Agriculture*, **24**(4): 649-654.

Jittanit, W. 2011. Kinetics and temperature dependant moisture diffusivities of pumpkin seed during drying. *Kasetsart journal of natural science*, **45**: 147-158.

Kashaninejad, M., Mortazavi, A., Safekordi, A. and Tabil, L.G. 2007. Thin-layer drying characteristics and modeling of pistachio nuts. *Journal of food Engineering*, **78**: 98-108.

Mbah, B.O., Eme, P.E. and Ogbusu, O.F. 2012. Effect of cooking methods (Boiling and Roasting) on nutrients and anti-nutrients content of *Moringa oleifera* seeds. *Pakistan Journal of nutrition*, **11**(3): 211- 215.

Menka, T., Nagraja, G.P., Yogesh, D.B., Sunilkumar, U.S. and Prakash, L. 2011. Physicochemical properties of flour and isolated starch from jackfruit seed. *RUGHS Journal of Pharmaceutical Sciences RJPS*, April-June, **1**(1): 58-63.

Nwosu, J.N. 2010. The effects of processing on the functional properties of 'Oze' (*Bosqueia angolensis*) Seeds. *Pakistan Journal of Nutrition*, **9**(8): 781-786.

Ocloo, F.C.K., Bansa, D.W.S., Boatin, R., Adom, T. and Agbemavor, W.S. 2010. Physico-chemical, functional and pasting characteristics of jackfruit seed. *Agriculture and Biologlogical Journal of North America. Agric. Biol. J. N. Am.*, **1**(5): 903-908.

Odoemelam, S.A. 2005. Functional properties of raw and heat processed jackfruit seed flour. *Pakistan Journal of Nutrition*, **4**(6): 366-370.

Ojediran, J.O. and Raji, A.O. 2010. Thin layer drying of millet and effect of temperature on drying characteristics. *International food research journal*, **17**: 1095-1106.

Okorie, S.U. 2010. Chemical composition of *Artocarpus communis* (Breadfruit) seed flour as affected by processing (Boiling and Roasting). *Pakistan Journal of nutrition*, **9**(5): 419- 421.

Ozdemir, M. and Devres, Y.O. 1999. The thin layer drying characteristics of hazelnuts during roasting. *Journal of food Engineering*, **42**: 225-233.

Panchariya, P.C., Popovic, D. and Sharma, A.L. 2002. Thin layer modeling of black tea processing. *Journal of food Engineering*, **52**: 349-357.

Radhika, G.B., Satyanarayana, S.V. and Rao, D.G. 2011. Mathematical model on thin layer draying of finger-millet (*Elusine coracana*). *Advance Journal of food science and technology*, **3**(2): 127-131.

Ranganna, S. 1986. Handbook of Analysis and Quality Control for Fruits and Vegetables products, Tata McGraw- Hill Publishing Company Limited, New Delhi.

Sacilik, K. 2007. Effect of drying methods on thin-layer drying characteristics of hull-less seed pumpkin (*Cucurbita pepo L.*). *Journal of food Engineering*, **79**: 23-30.

Seena, S., Sridhar, K.R., Arun, A.B. and Young, C.C. 2006. Effect of roasting and pressure-cooking on nutritional and protein quality of seeds of mangrove legume (*Canavalia cathartica*) from southwest coast of India. *Journal of food composition and analysis*, **19**: 284- 293.

Tavakolipour, H. 2011. Drying of Pistachio nuts (*pistica vera L.*). *World applied sciences Journal*, **12**(9): 1639-1646.

Tulayatan, V., Tananuwonga, K., Songjinda, P. and Jaiboonb, N. 2002. Some physico-chemical properties of jackfruit seed flour and starch. *Science Asia*, **28**: 37-41**.**