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Research Paper

Development of Powder from Amaranthus by Convective Hot Air Drying at Varied Temperatures and its Quality Evaluation

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ABSTRACT

In the present investigation Amaranthus (*Amaranthus spinosus*) leaves were dried in a convective hot air dryer at 45°C, 55°C and 65°C. The air velocity inside the dryer was 2-3 m/s, and the drying process was completed within 5.5 hrs to 10.5 hrs. The drying rate increased with an increase in air temperature ,thus reducing the drying time. The experimental drying data of amaranthus were applied to three moisture ratio models, Newton, Page, Henderson, and Pabismodels. Among all the models, the Page model was found to be the best for explaining the drying characteristics of amaranthus leaves. The effective moisture diffusivity varied from 3.114×10^{-10}, 5.735×10^{-10}, and 7.729×10^{-10} over the temperature range studied, with an activation energy was 40.728 kJ/mol for amranthus leaves. The nutritional values like protein decreased from 10.32 to 10.07 %, fiber decreased from 20.73 to 19.05%, fat increased from 2.41 to 2.92%, the water absorption capacity increased from 9.29 to 9.82 g/ml while wettability decreased from 194.4 sec to 82.61 sec as the temperature of drying increases from 45°C to 65°C.

Keywords: Leafy vegetables, dehydration, activation energy, nutritional value, functional properties

The leafy vegetables are highly perishable in nature and, therefore, have a very short shelf life. Green leafy vegetables represent an excellent component of the habitual diet in tropical and temperate countries.

Green leafy vegetables have long been recognized most abundant sources of protein, vitamins, minerals, and antioxidants. Vitamins like ascorbic acids, phenols etc., are important in human food since they function as an anticancer agent (Meena *et al.* 2016).

Amaranthus (*Amaranthus spinosus*) originated in America and is one of the oldest food crops in the world. The genus Amaranth consists of nearly 60 species, several of which are cultivated as leafy vegetables, grains, or ornamental plants, while others are weeds. It is a very common Indian plant is known for its medicinal properties and commonly known as 'spiny amaranth' or 'pigweed', "*Kate wali Chaulai* (*Kanatabhajii*)" in 'Hindi", cultivated throughout India, and Sri Lanka and distributed throughout the tropics and warm temperate regions of Asia from Japan to Indonesia, the Pacific islands and Australia (Kumar *et al*. 2014) Grain amaranth species have been important in different parts of the world and at various times during the past few thousand years. At present, amaranth is extensively grown as a green, leafy vegetable in many temperate and tropical regions. It supplies a substantial part of the

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protein13.56 g, fibers 6.7 g, carbohydrates 62.25 g, fat 7.02 g, vitamin C 4.2 mg, minerals like calcium 159 mg, phosphorus 557 mg, iron 7.61 mg, potassium 508 mg per 100 g in the diet (USDA, 2009).

Drying is one of the oldest methods of food preservation, and it represents a very important aspect of food processing. The advantage of dried foods is that they have decreased moisture content, which reduces thermodynamic water activity, thus preventing the growth of microorganisms that cause the spoilage reaction (Vega-Galvez *et al*. 2009). Besides, drying helps to achieve longer shelf life, lighter weight, lesser storage space, and lower packing and transportation costs (Arabhosseini *et al.* 2009). Drying not only affects the water content of the product but alters other physical, biological, and chemical properties such as enzymatic activity, microbial spoilage, viscosity, hardness, aroma, flavor, and palatability of foods. To obtain high-quality dehydrated vegetables, the drying process should allow effective retention of color, flavor, texture, taste, and nutritive value (Kuppuswamy and Rao, 1970).

The most common methods widely used for drying are open sun drying and solar drying. However their disadvantages include the inability to handle large quantities and to achieve consistent quality standards, contamination problems, long drying times, and low energy efficiency, which is not desirable for the food industry. Hot-air drying is widely applied in the food industry. Compared with natural drying methods, hot-air drying is less influenced by climatic conditions, reducing the drying cycle and improving hygienic conditions (Fang, Wang, and Hu, 2009).

Drying is a simultaneous heat and mass transfer process, which induces changes in the material during drying. Mathematical models of the drying process are used for designing new or improving existing drying systems and controlling the drying process (Menges and Ertekin, 2006). Many mathematical models have been proposed to describe the drying process, of which thin-layer drying models have been widely in use (Doymaz, 2012). Various researchers have studied the drying behavior with different drying models i.e., Lewis, Henderson, and Pabis, Logarithmic, Newton, Modified Henderson and Pabis, Page, Midilli *et al.* Verma *et al.* Wang and Sing, Two terms, Weibull, Modified page, Two-term exponential, Parabolic and Approximation of diffusion among that Wang and sing and Midilli *et al., the* model was best fitted for grape leaves (Doymaz, 2012); Page model was best fitted for mint leaves, chard leaves, fever leaves, and spinach leaves (Park *et al.* 2002; Alibas, 2006; Sobukola and Dairo, 2016; Dadali *et al.* 2008) respectively. Midilli *et al.* and the Parabolic model was best fitted for bay laurel leaves (Doymaz, 2014); the Modified page was best fitted for kale (Mwithiga and Olwal, 2005). However, the information for the drying behavior of amaranthus is very scarce.

The present investigation aims to study the drying characteristics of the amaranthus at varied temperatures i.e., 45, 55, and 65°C. And the effect of drying temperature on the quality characteristics of dehydrated amaranthus i.e. protein, fat, ash, fiber, carbohydrates, color, and some functional properties i.e., wettability and water absorption capacity was studied.

1. MATERIALS AND METHODS

The Amaranthus (*Amaranthus spinosus*) bunches were procured from the local market of Roha (Maharashtra), India. The bunches were washed, and leaves were separated from stalks. The surface moisture from the leaves was removed.

1.1 Moisture content

The moisture content of amaranthus leaves was determined as per AOAC, 2010. The initial moisture content of amaranthus leaves was determined by the hot air oven method at 105°C ±1°C for 24 hours. The final weight of amaranthus leaves was recorded after 24 hours. The moisture content of the amaranthus leaves was determined by following the formula (Chakraverty, 1994).

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

Where,

W_1 = Weight of sample before drying, *g*

W_2 = Weight of sample after drying, *g*

1.2 Convective hot air drying

Convective hot air drying of amaranthus was performed at the 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. Aditi Associates, India; Model:ATD-124), having a capacity of 5 kW.

There were nine numbers of perforated trays were placed inside the convective hot air dryer. The size of the tray was 81 cm × 41 cm × 3.4 cm. The leaves were spread on the tray in a single layer. The mesh (square) size of the tray was 1 × 1 mm. The temperature of the drying was 45°C, 55°C and 65°C. The air velocity inside the dryer was 2-3 m/s. The weight loss with respect to the time was recorded from trays at different locations in the convective hot air dryer. The moisture content with respect to time was calculated from drying data. The drying data includes initial moisture content, moisture content with respect to time, drying rates with respect to moisture content, and moisture ratios with respect to time of amranthus were recorded. Three replications were taken for each experiment.

1.3 Moisture ratio

The moisture ratio of amranthus was calculated using the following formula (Chakraverty, 2005).

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

Where,

MR = Moisture ratio

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

M_e = Equilibrium Moisture Content, % (db)

M_0 = Initial moisture content, % (db)

1.4 Drying model

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

Table 1: Mathematical models tested with the moisture ratio of amranthus

Sl. No.	Model	Equation	Reference
1	Newton	MR = exp (-kt)	Westerman *et al.* 1973
2	Page	MR = exp ($-kt^n$)	Zhang and Litchfield, 1991
3	Henderson and pabis	MR = aexp (-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 minutes of amaranthus with convective hot air drying. The moisture ratio determines the unaccomplished moisture change, defined as the ratio of the free water still to be removed at time *t* over the initial total free water (Henderson and Pabis, 1961).

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

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

Where,

MR_{exp} = experimental moisture ratio

MR_{pre} = predicted moisture.

N and *n* are the number of observations and the number of constants, respectively (Togrul and Pehlivan, 2004).

1.5 Correlation regression 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 the lower value of RMSE values, the better the equation fitting (goodness of fit) (Ozdemir *et al.* 1999; Ertekin and Yaldiz, 2004; Wang *et al.* 2007). According to Wang *et al.* (2007) reduced chi-square (χ^2) and root mean square error (RMSE) can be calculated as follows equation

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

Where,

$MRexp,i$ = is the i^{th} experimental moisture ratio,

$MR\ pre,i$ = is the i^{th} predicted moisture ratio,

N = is the number of observations, and

z = is the number of constants.

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

1.6 Effective moisture diffusivity

The effective moisture diffusivity was calculated by using the simplified Fick's second law of diffusion model (Doymaz, 2004) as given in Eq (5).

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

Where,

M = moisture content (kg water/kg dry matter); t = the time (s); D_{eff} = the effective moisture diffusivity,(m^2/s); ∇^2 = the differential operator.

The solution of Fick's second law in slab geometry, with the assumption that moisture migration was caused by diffusion, negligible shrinkage, constant diffusion coefficient, and temperature, was given by Crank (1975) as follows:

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

Where,

H = is the half thickness of the slab m;
n = 1, 2, 3 … the number of terms taken into consideration.

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

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

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

Where,

L= half thickness

1.7 Determination of activation energy

The effective moisture diffusivity of the samples was estimated by using the simplified mathematical Fick's second diffusion model (Eq 9). The activation energy of the samples was obtained by plotting the natural logarithm of D_{eff} against the reciprocal of absolute temperature, then determining the slope of the straight line by using (Eq 8). Lopez *et al.* (2000) and Simal *et al.* (1996).

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

Where,

D_o = the pre-exponential factor of the Arrhenius equation, (m^2/s)

E_a = the activation energy (kJ/mol)

T = the temperature of air, (°C)

R = the universal gas constant, (8.134kJ/mol·K),

Rearranging Eq (9) gives Eq (10):

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

The energy of activation can thus be calculated from Eq (10), which gives a relationship between temperature and effective moisture diffusivity. The plot of $ln(D_{eff})$ versus $1/(T + 273.15)$ gives a straight line (slope of $K_L = E_a/R$). Linear regression analyses were used to fit the equation to the experimental data to obtain the coefficient of determination (r^2).

1.8 Preparation of powder

The dried leaves of amaranthus were ground by a mixer-grinder to an average particle size 0.2 mm to make fine powder.

1.9 Physico-chemical analysis and functional properties of amaranthus powder

1.9.1 Moisture content

The moisture content of amaranthus powder dried at 45°C, 55°C and 65°C was determined as per AOAC, 2010. The moisture content was determined by the hot air oven method at 105°C ± 1°C for 24 hours. The final weight of the dried amaranthus powder sample was recorded after 24 hours. The moisture content of the dried amaranthus powder was determined by following the formula (Chakraverty, 1994). Each observation was recorded three times to get the replication average moisture content was reported.

$$\text{Moisture content (db)\%} = \frac{W_1 - W_2}{W_1} \times 100 \quad \ldots(11)$$

1.9.2 Protein

Protein content in the amaranthus powder was determined by the amicro-Kjeldahl distillation method (AOAC 2000). The dried powder sample of amaranthus leaves at 45, 55, and 65°C was digested by heating with concentrated sulphuric acid (H_2SO_4) in the presence of a digestion mixture, potassium sulphate (K_2SO_4) and copper sulphate ($CuSO_4$).

The mixture was then 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 percent nitrogen content of the sample was calculated by the formula given below. Total protein content was calculated by multiplying the amount of percent nitrogen with an appropriate factor (6.25). The observations were repeated three times to get the replication.

$$\%N = 1.4 \times \frac{(mLHCL - mLblank) \times Conc.\,of HCL}{Weight of sample\ (g)} \quad \ldots(12)$$

% Protein = % N × Factor (6.25).

1.9.3 Crude fat (%)

Crude fat of amaranthus powder dried at 45, 55, and 65°C was estimated as crude ether extract of the dry material. The dry sample of amaranthus powder (5g) was weighed accurately into a thimble and plugged with cotton. The thimble was then placed in a soxhlet apparatus and extracted with anhydrous ether for 3 hrs. The ether was then evaporated, and the flask with the residue dried in an oven at 80°C to 100°C, cooled in a desiccator, and weighed. The fat content was expressed as g/100g (AOAC, 1995). The experiment was repeated three times to get the replication.

$$\text{Crude fat content (g/100g)} = \frac{\text{Weight of ether extracted}}{\text{Weight of sample taken}} \quad \ldots(13)$$

1.9.4 Ash (%)

The tare weight of three silica dishes (7-8 cm dia) were noted, and 5 g of the amaranthus powder sample prepared from 45, 55, and 65°C drying temperature was weighed into each silica dish. The contents were ignited on a Bunsen burner, and the material was ashed at not more than 525°C for 4 to 6 hr, in a muffle furnace. The dishes were cooled and weighed. The difference in weights represented the total ash content and was expressed as a percentage (Rangana, 1986). The experiment is repeated three times to get the replication.

$$\text{Ash (\%)} = \frac{\text{Weight of crucible with ash} - \text{Weight of crucible}}{\text{Weight of sample}} \times 100 \quad \ldots(14)$$

1.9.5 Crude fibre (%)

About 2–5 g of moisture and fat-free sample of amaranthus powder prepared at 45, 55, and 65°C available in filter paper from the fat extraction method (Ranganna, 1986) were weighed into a 500 ml beaker and 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 0.313 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 free from alkali, followed by washing with alcohol and ether. It was then transferred to a crucible, dried overnight at 80°C to 100°C, and weighed. The crucible was heated in a muffle furnace at 525°C for 2 to 3 hrs, cooled, and weighed again. The difference in the weights represented the weight of crude fiber (Rangana, 1986). Observations were recorded three times to get the replication. The average reading was reported.

Crude Fiber (g/100g) =

$$\frac{100-(\text{Moisture+Fat}) \times \text{Weight of Fiber Weight}}{\text{Weight of sample taken (Moisture + Fat free sample)}} \times 100 \qquad \ldots(15)$$

1.9.6 Carbohydrates:

Carbohydrate content of amaranthus powder prepared at 45, 55, and 65°C was determined by subtracting the total sum of protein, fiber, ash, and fat from the total dry matter (James, 1995). The carbohydrate was calculated by using the following equation (16);

%carbohydrate = 100 – % protein + % fat + % fiber + % ash + % moisture content …(16)

1.9.7 Colour

The dried powder of amranthusat 45, 55 and 65°C was used to measure the colour value by using a colorimeter (M/S Konica minotta, Japan model-Meter CR-400). The equipment was calibrated against standard white tile and black tile. Around 20 g of amaranthus powder was taken in the glass cup, the cup was placed on the aperture of the instrument. The color was recorded in terms of L= lightness (100) to darkness (0); a = Redness (+60) to Greenness (-60); b= yellowness (+60) to blueness (-60). Each observation was recorded 3 times for replication.

1.9.8 Wettability

The 100 ml of distilled water at 25°C was poured into a 400 ml beaker (diameter 70 mm). A glass funnel (height 100 mm, lower diameter 40 mm, upper diameter 90 mm) was placed and maintained on the upper edge of the beaker. A test tube was placed within the funnel to block the lower opening of the funnel. 3g dried powder of amaranthus at 45, 55 and 65° was placed in the test tube; while the timer was started, the tube was simultaneously elevated. Finally, the time is recorded when the powder is completely wet (visually assessed that all powder particles have diffused into the water) (Nguyen *et al*. 2005) the observations were recorded three times to get the replication, average reading was reported.

1.9.9 Water absorption capacity

The water absorption capacity of dried leaves powder of amaranthus at 45, 55, and 65°C was determined using the method of Sosulski (1976) with slight modifications. The sample, 3 g was dispersed in 25 ml of distilled water and placed in pre-weighed centrifuge tubes. The dispersions were 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. Each observation was recorded 3 times to get the replication.

2. RESULTS AND DISCUSSION

2.1 Convective hot air drying of amranthus

Fig. 1 shows moisture content (db) % with respect to time (min) of amaranthus dried by convective hot air dryer. The amaranthus was dried from average initial moisture content of 851.01% (db) to 5.1127% (db) at 45°C; 450.14% (db) to 6.2016% (db) at 55°C; 608.47% (db) to 5.9952% (db) at 65°C respectively. It took around 10.5 h, 7 h, and 5.5 h time to dry the product at 45°C, 55°C, and 65°C, respectively. Fig.3.2 shows the drying rate (g water removed/100 g of bone dry material; /min) with respect to moisture content % (db) of amaranthus dried by convective hot air drying at 45°C, 55°C, and 65°C. The initial drying rate of amaranthus was 5.422 × 10^{-2} g of water removed / 100 g of bone dry matter per minute and decreased up to the 9.536 × 10^{-3} g of water removed / 100 g of bone dry matter per minute at 45°C; 0.211 g of water removed / 100 g of bone dry matter per minute and decreases up to the 4.312 × 10^{-2} g of water removed / 100 g of bone dry matter per minute at 55°C; 0.201 g of water removed / 100 g of bone dry matter per minute and decreases up to the 5.859 × 10^{-2} g of water removed / 100 g of bone dry matter per minute at 65°C.

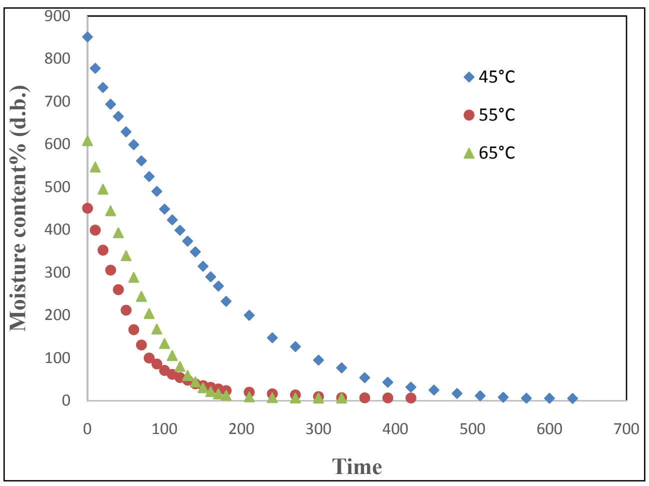

Fig. 1: Moisture content %(db) versus time (min) by convective hot air drying at different temperatures for amaranthus

From Fig. 2 it could be seen that the drying took place in a falling rate period. As the temperature of drying increases from 45°C to 65°C, the drying rate also increases. Moisture removal inside the amaranthus at 65°C was higher and faster than the other investigated temperatures. The migration of surface moisture and evaporation rate from the surface to the air decreases with a decrease in the moisture in the product. A shorter time of drying was observed at higher temperatures, thus increasing the drying rate (Zhu and Shen, 2014). This increase in drying rate is because of the increased heat transfer potential between the air and amaranthus, which favors the evaporation of water from amaranthus. Similar observations reported in the literature for Parsley leaves, fever leaves, and chard leaves by Akpinar *et al.* (2006), Sobukola and Dairo, (2007), and Ilkunur Alibas (2006). The drying rate values are in agreement with the values obtained for nettle and mint leaves, spinach, and Grape leaves reported by Kaya and Ayadin (2009), Doymaz (2009), and Doymaz (2012), respectively.

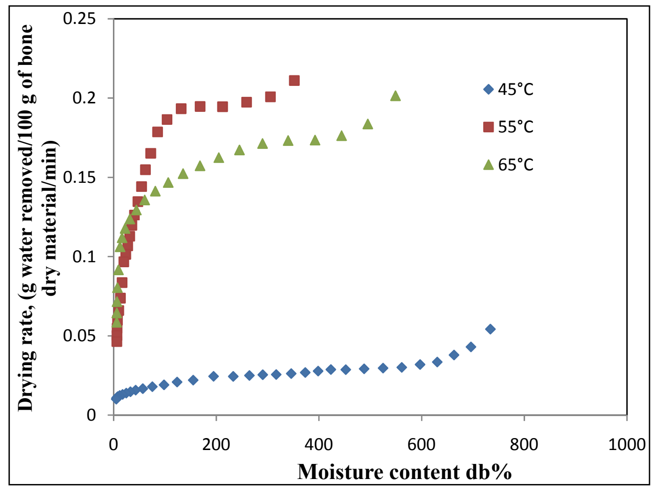

Fig. 2: Drying rate (g water removed/100 g of bone dry material/min) versus moisture content % (db) of amaranthus dried by convective hot air drying method at different drying temperature

Fig. 3 shows the variation in moisture ratio with respect to time in minutes. During the drying experiment moisture ratio decreased from 1 to 1.2 × 10^{-7}, 1 to 1.12 × 10^{-8} and 1 to 8.02 × 10^{-7} at the drying temperature of 45°C, 55°C, and 65°C, respectively. A similar trend was observed in agreements with those reported by Doymaz, 2009 for spinach leaves, Alibas, 2006 for chard leaves; and Mwithiga and Olwal, 2005 for kale.

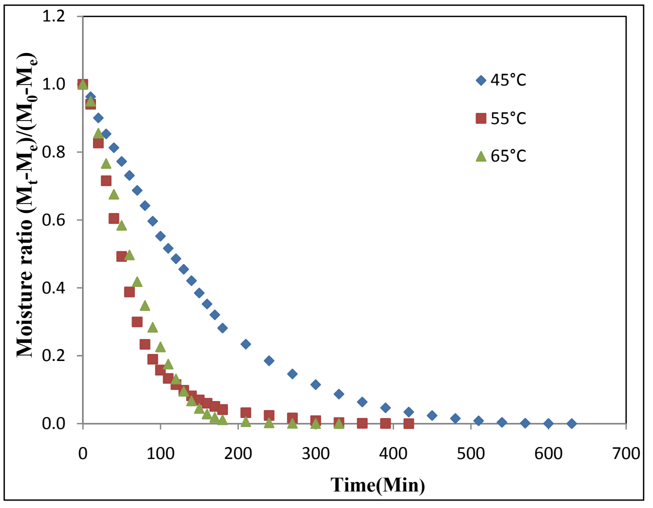

Fig. 3: Variation in moisture ratio with respect to time, min for amaranthus during convective hot air drying

2.2 Evaluation of thin layer-drying model of amaranthus dried by convective hot air drying

Table 1 (a), 1 (b), 1(c) shows the model parameters of various models fitted to the experimental data for the Newton model, Page model, Henderson, and Pabis, etc. at 45°C, 55°C and 65°C by convective hot air drying of amaranthus respectively. Among the models fitted to the experimental data at 45°C, 55°C and 65°C the Page model was well fitted to the experimental data with $R^2 \geq 0.997$; MSE ≤ 2.357×10^{-4} and chi-square (χ^2) ≥ 5.893×10^{-3}. Non-Linear regression analysis was done according to the three thin layer models for moisture ratio data. Table 3.1 (a), (b) and (c) shows the statistical regression results of the different models, including the drying model coefficients and comparison criteria used to evaluate

Table 1: Model parameters, R^2, RMSE and Chi square values of amaranthus dried by Convective hot air drying at 45°C, 55°C and 65°C

Table 1(a): Convective hot air drying at 45°C temperature

Sl. No.	Model name	Temperature			
		45°C			
		Model Parameter	R^2	MSE	χ^2
1	Newton	$k=6.746\times10^{-3}$	0.996	7.613×10^{-4}	2.512×10^{-2}
2	Page	$k=2.895\times10^{-3}$ n=1.170	0.998	1.512×10^{-4}	4.840×10^{-3}
3	Henderson and Pabis	a=1.037 $k=7.049\times10^{-3}$	0.995	6.189×10^{-4}	0.0198

Table 1 (b): Convective hot air drying at 55°C temperature

Sl. No.	Model name	Temperature			
		55°C			
		Model Parameter	R^2	MSE	χ^2
1	Newton	$k= 1.749\times10^{-2}$	0.993	7.809×10^{-4}	2.030×10^{-2}
2	Page	$k=7.735\times10^{-3}$ n=1.194	0.997	2.357×10^{-4}	5.893×10^{-3}
3	Henderson and Pabis	a=1.056 $k=1.845\times10^{-2}$	0.993	5.561×10^{-4}	0.013

Table 1(c): Convective hot air drying at 65° temperature

Sl. No.	Model name	Temperature			
		65°C			
		Model Parameter	R^2	MSE	χ^2
1	Newton	k= 0.015	0.987	2.686×10^{-3}	6.179×10^{-2}
2	Page	$k=2.741\times10^{-3}$ n=1.390	0.998	2.215×10^{-4}	4.873×10^{-3}
3	Henderson and pabis	a=1.085 $k=1.625\times10^{-2}$	0.984	2.069×10^{-3}	0.045

the goodness of the fit, including the R^2, χ^2 and RMSE of amaranthus at different temperature. In all cases, R^2 values for the models were greater than 0.997, indicating a good fit. The model parameter i.e.' k' was 2.895 × 10^{-3}, 7.735 × 10^{-3}, and 2.741 × 10^{-3} at 45°C, 55°C and 65°C respectively. Value' n' was 1.170, 1.194, and 1.390 for the 45°C, 55°C and 65°C respectively. The 'k' value increases with increase in temperature from 40°C to 55°C. But it decreases at 65°C .'n' value increases with the increase in the temperature. For all the temperature from 45°C to 65°C.

2.3 Effective moisture diffusivity of amaranthus dried by convective hot air drying

Fig. 4 shows Ln (MR) versus time (minute) for convective hot air drying of amaranthus dried at 45°C, 55°C, and 65°C, respectively. The graph shows the straight line curve. The straight line equation y= mx+c where the m is the slope of the line. Effective diffusivity (D_{eff}) at a time for amaranthus was calculated by Eq (7). Table 2 shows the effective diffusivity of amaranthus dried at 45°C, 55°C and 65°C. The effective diffusivity values were in the range of 3.114 × 10^{-10} to 7.729 × 10^{-10} for all the temperatures. As the temperature increases, the diffusivity value increases from 3.114 × 10^{-10}, 5.735 × 10^{-10} and 7.729 × 10^{-10} at 45°C, 55°C and 65°C respectively. The effective diffusivity is used to explain the mechanism of moisture movement during drying and the complexity of the process (Kashaninejad *et al.* 2007; Falade and Solademi, 2010). Generally, effective moisture diffusivity increases with increased air temperature (Falade and Solademi, 2010).

It was observed that Deffvalues increased greatly with increasing drying temperature and thickness. When samples are dried at higher temperatures, increased heating energy will 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 were 3.114 × 10^{-10}, 5.735 × 10^{-10} and 7.729 × 10-10 m^2/s during the drying temperature of

45°C, 55°C and 65°C respectively. Similar results have been observed. The values of Deff obtained from this study lie within the general range 10^{-12} – 10^{-8} m^2/s for drying of food materials (Zogas *et al.* 1996). Similar results are found to correspond well with those existing in the literature, such as for spinach ranging from 16.590 ×10^{-10} to 1.927 ×10^{-9} m^2/s (Doymaz, 2009); 0.295 – 3.60 ×10^{-9} m^2/s for olive leaves (Nourhéne *et al.* 2008); 1.021 –10.44 × 10^{-9} m^2/s for Mexican tea leaves (Ethmane Kane *et al.* 2008); 1.49–5.59 × 10^{-10} m^2/s for kale (Mwithiga and Olwal, 2005); and 1.744 – 4.992 × 10^{-9} m^2/s for neetle and mint leaves (Kaya and Aydin, 2009).

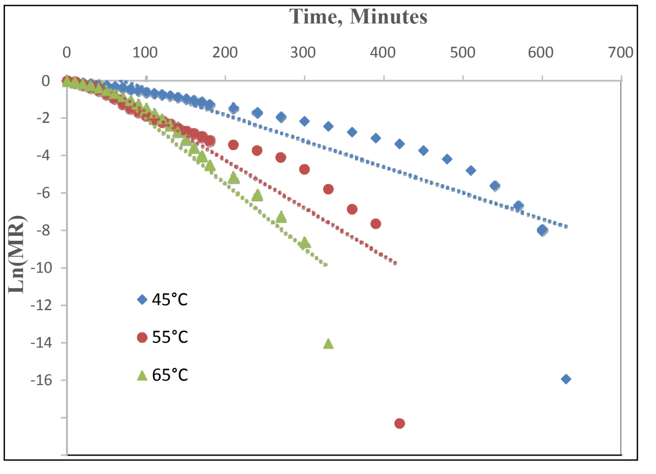

Fig. 4: *Ln*(*MR*) versus time, minutes for effective diffusivity for convective hot air drying of amaranthus

2.4 Activation energy for amaranthus dried by convective hot air drying

Fig. 5 shows the *Ln*(D_{eff}) vs 1/T_{abs} for dried amaranthus at 45°C, 55°C, and 65°C. The activation energy was calculated by plotting the natural logarithm of D_{eff} vs reciprocal of absolute temperature, which showed a straight line in the range of air temperature studied. The activation energy E_a for moisture diffusion calculated from the slope of straight-line graphs are given in Table (2). The activation energy for moisture diffusion was found to be 40.728 kJ/mol. The energy of activation (E_a) reported in the literature for convective hot air drying of spinach was 34.35 kJ/mol (Doymaz, 2009). It is lower than the activation energy of mint leaves, 82.928 kJ/mol (Park *et al.* 2002), and the fever leaves drying 80.78 kJ/mol (Sobukola and Dairo, 2007) it is more than the E_a of bay laurel leaves which is 36.48 kJ/mol (Doymaz, 2014); kale drying 36.115 kJ/mol (Mwithiga and $1/T_{abs}$ Olwal, 2005).

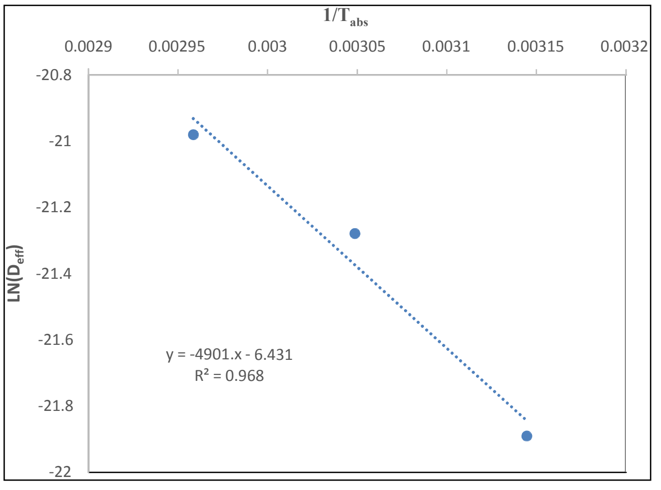

Fig. 5: $Ln(D_{eff})$ vs $1/T_{abs}$ for dried amaranthus leaves dried by convective hot air drying method

Table 2: Values of effective diffusivity and activation energy of amaranthus at different temperatures

Temperature, °C	D_{eff}(m^2/s)	Ea (kJ/mole)
45°C	3.114×10-10	
55°C	5.735×10-10	40.728
65°C	7.729×10-10	

The results indicated a linear relationship between $Ln(D_{eff})$ and $(1/T_{abs})$ as plotted in Fig. (5) for amaranthus dried by convective drying at 45°C, 55°C, and 65°C. The diffusivity constant or pre-exponential factor of the Arrhenius equation (D_0) and activation of energy (E_a) calculated from the linear regression are 1.61 × 10^{-3} m^2/s and 40.728 kJ/mol for amaranthus. The relationship between D_{eff} and the activation energy of spinach leaves are given in Eq. (16);

$$D_{\text{eff}} = (1.61 \times 10^{-3}) \exp\left(-\frac{40.728}{R(T+273.15)}\right) \quad \ldots(16)$$

2.5 Physico-chemical and functional properties of dried amaranthus powder

Table 3 shows the physicochemical and functional properties i.e., moisture content, protein, fat, ash, fiber, carbohydrate, wettability, color L, a, and b of dried amaranthus powder at 45, 55, and 65˚C.

2.5.1 Moisture

Table 3 (a) shows the moisture content of amranthus powder. Moisture content varied for amaranthus powder ranged was 5.56±0.22, 6.18±0.10 and 7.06±0.15 at 45˚C, 55˚C and 65˚C respectively. The highest moisture content for amranthus is observed at 65˚C. The moisture of amranthus was significant at $p \leq 0.01$. A similar result was observed by (Rajeshwari *et al.* 2013) reported that the moisture content of the amaranthus powder was 3.72 percent.

2.5.2 Protein

Table 3(b) shows the (%) protein content for amaranthus powder. Protein content varied for amranthus powder was 10.32±0.01%, 10.21±0.01%, and 10.07±0.02% at 45˚C, 55˚C, and 65˚C respectively. Highest protein content is observed at 45˚C of amranthus powder. The protein content decreased with an increase in temperature from 45˚C to 65˚C. The decrease in protein content w. r. t. increase in temperature was significant at $p \leq 0.01$. The results are in agreement with the protein content of amaranthus powder was 17.81% (Rajeshwari *et al.* 2013), and the protein content observed in spinach powder is 19.10% (Kavitha and Ramdas, 2013).

2.5.3 Fat

Table 3(c) shows the (%) fat content of amranthus powder. Fat content varied for amranthus powder it was 2.41±0.02 (%), 2.81±0.02(%) and 2.92±0.01 (%) at 45˚C, 55˚C and 65˚C respectively. Highest fat content is observed in 65˚C of amranthus powder. The increase in fat was significant at $p \leq 0.01$. The fat content observed in dried spinach powder is 7.11% (Kavitha and Ramdas, 2013), similar results were observed by Joshi and Mehta, 2010 who reported that the fat content of oven-dried moringa leaf powder was 7.01%.

2.5.4 Ash

Table 3(d) shows the ash content for amaranthus powder. Ash content varied for amaranthus powder 5.90±0.02(%), 5.42±0.02 (%) and 5.40±0.04 (%) at 45˚C, 55˚C and 65˚C respectively. Highest ash content was

Table 3: Physico-chemical and functional properties of dried amaranthus powder

Sl. No.	Chemical constituent	Amaranthus			SE (@p≤0.01)	CD (@p≤0.01)
		45°C	55°C	65°C		
a	Moisture % (w.b.)	5.56±0.22	6.18±0.10	7.06±0.15	0.094	0.326
b	Protein	10.32±0.01	10.21±0.01	10.07±0.02	0.006	0.022
c	Fat	2.41±0.02	2.81±0.02	2.92±0.01	0.009	0.031
d	Ash	5.90±0.02	5.42±0.02	5.40±0.04	0.016	0.057
e	Fiber	20.73±0.56	19.36±0.01	19.05±0.07	0.188	0.650
f	Carbohydrate	55.08±0.40	56.03±0.10	55.47±0.24	0.159	0.553
g	Colour L	57.53±0.03	55.86±0.01	55.87±0.01	0.010	0.034
h	Coloura	15.94±0.03	15.62±0.01	18.03±0.02	0.013	0.044
i	Colour b	25.06±0.03	27.23±0.01	27.87±0.01	0.009	0.030
j	Wettability (sec)	194.4±3.93	84.0±5.13	82.61±11.06	4.271	14.779
k	Water absorption capacity(g/ml)	9.29±0.07	9.50±0.06	9.82±0.04	0.033	0.115

observed in 45˚C of amranthus powder. The ash content decreases with an increase in temperature 45˚C to 65˚C. The change in ash was significant at p≤0.01. The Rajeshwari *et al.* (2013) reported the ash content of amaranthus powder was 16.24 %.

2.5.5 Fiber

Table 3(e) shows the fiber content of amranthus powder. Fiber content varied for amranthus powder ranged was 20.73±0.56 (%), 19.36±0.01 (%) and 19.05±0.07 (%) at 45˚C, 55˚C and 65˚C respectively. Highest fiber content is observed at 45˚C drying temperature. The fiber content decreases w. r. t. the increase in temperature was significant at p≤0.01. Joshi and Mehta, 2010 reported that the fiber content of oven-dried moringa leaf powder was 11.8 %. Kannan and Thahaaseen, (2016) reported 8.83 % fiber content in shade- dried and 6.5 % in oven-dried moringa leaf powder.

2.5.6 Carbohydrate

Table 3(f) shows the carbohydrate content for amaranthus powder. Carbohydrate content varied for amranthus powder ranged was 55.08±0.40 (%), 56.03±0.10 (%) and 55.47±0.24 (%) at 45˚C, 55˚C and 65˚C respectively. The highest carbohydrate content was observed at 55˚C drying temperature powder. The variation in carbohydrate content with an increase in temperature was significant at p≤0.01. Joshi and Mehta, 2010 reported that the carbohydrate content of oven-dried moringa leaf powder was 28.3%, Kannan and Thahaaseen, 2016 reported 28.6% for oven-dried moringa leaf powder.

2.5.7 Colour

Table 3(g) shows the color 'L' for amaranthus powder dried at 45, 55, and 65˚C. 'L' value for 45˚C, 55˚C and 65˚C was 57.53±0.03, 55.86±0.01 and 55.87±0.01 respectively.

Table 3 (h) shows the colour 'a' value for amaranthus powder dried at 45˚C, 55˚C and 65˚C was 15.94±0.03, 15.62±0.01 and 18.03±0.02 respectively and Table 3 (i) shows the color 'b' value for amaranthus powder dried at 45˚C, 55˚C, and 65˚C was 25.06±0.03, 27.23±0.03 and 27.87±0.01 .The increase in 'a' value shows the increase in the green color of powder with an increase in temperature the highest L, a, and b values shows at 65˚C. Similar results were observed in chard leaves, where color is increased with an increase in temperature(Alibas, 2006); similarly the darkness 'a' value were increased with increased temperature observed in spinach (Ankita and Prasad, 2013).

2.5.8 Wettability

Table 3(j) shows the wettability of amaranthus powder. Wettability varied for amaranthus powder ranged from 194.4±3.93 sec 82.0±5.13 and 82.61±11.06 sec at drying temperature increase from 45˚C to 65˚C respectively. Highest wettability is observed at a drying temperature of 45˚C of amaranthus powder. The change in wettability at varied temperatures of drying was significant at p≤0.01. Gulia *et al.* (2010) reported the wettability of Aloe vera powder ranged was 35 to 37 sec at 50, 60, 70, and 80˚C respectively.

2.5.9 Water absorption capacity

Table 3 (k) shows the water absorption capacity for amaranthus powder. Water absorption capacity for amaranthus powder varied in the range of 9.29±0.07 (g/ml), 9.50±0.06 (g/ml) and 9.82±0.04 (g/ml) respectively. Highest water absorption capacity was observed at 65˚C of amaranthus powder. The increase in water absorption capacity was significant at p≤0.01. Ankita and Prasad, 2013 reported that the water absorption capacity of spinach leaves powder ranged from 2.422±0.019-2.588±0.09 g/g. Olua *et al.* (2015) reported that the 1.200±0.00 (g/ml) of water absorption capacity for cashew apple powder respectively.

CONCLUSION

The drying of amaranthus leaves occurred in the falling rate period. It took around 10.5 hrs, 7 hrs, and 5.5 hrs to dry the product from 851.01% (db) to 5.1127% (db) at 45°C; 450.14% (db) to 6.2016% (db) at 55°C; 608.47% (db) to 5.9952% (db) at 65°C respectively. Experimental data of moisture ratio with respect to time of amaranthus drying were fitted the page model better describes than the other models i.e., Henderson and Pabis and Newton models. The effective moisture diffusivity varied from 3.114×10^{-10}, 5.735×10^{-10}, and 7.729×10^{-10} over the temperature range studied, and it increases with the increase of the air temperature. The activation energy of the amaranthus leaves was found as 40.728 kJ/mol. The protein, ash, and fiber content decreased from 10.32 to 10.07 %, 5.90 to 5.40 %, and 20.73 to 19.05 %with an increase in temperature, and the fat increased from 2.41 to 2.92 % with increased temperature, wettabilty is decreased from 194.4(sec) to 82.61(sec), and water absorption capacity is increased from 9.29(g/ml) to 9.82(g/ml) with increasing temperature from 45°C to 65°C. The better nutritional and functional properties have been observed at 450C compared with other temperatures.

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