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RESEARCH PAPER

Development of Powder from Spinach by Convective Hot Air Drying at Varied Temperature and its Quality Evaluation

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ABSTRACT

Dehydration is the most precious method for preservation of green leafy vegetables. Dehydration is the best option to preserve the green leafy vegetable during abundant production. In the present investigation Spinach (*Spinacia oleracea*) 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, the drying process completed within 5 hrs to 8.5 hrs, drying rate increased with increase in air temperature and thus reducing the drying time. The experimental drying data of spinach were applied to three moisture ratio models, namely, Newton, Page and Henderson and Pabis models. Among all the models, the page model was found to be the best for explaining the drying characteristics of spinach leaves. The effective moisture diffusivity varied from 1.77578×10^{-9}, 2.66367×10^{-9} and 3.60649×10^{-9} over the temperature range studied, with activation energy was 31.677 kJ/mol for spinach leaves. The nutritional values like protein decreased from 10.73 to 10.10 %, fiber decreased from 14.33 to 11.21%, ash is deceased from 6.70 to 6.31%, fat is increased from 3.04 to 3.11% as the temperature of drying increases from 45⁰C to 65⁰C the carbohydrate increases from 58.53 to 63.03 % with respect to increase in drying temperature, the functional properties i.e. wettability decreases from 82 to 42 sec and water absorption capacity increases from 7.57 to 8.77 g/ml with respect to the temperature of drying increases.

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

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. Many leafy vegetables especially spinach has attained commercial status and its cultivation is wide spread in India particularly northern states (Meena *et al*. 2016).

Spinach (*Spinacia oleracea*) is a cool season annual vegetable. It is an important leafy vegetable, now grown throughout the temperate regions of the world. The world production of the spinach is 275,600 metric tonnes (USDA, 2016). Spinach is widely used in making various foods like puree, soups and baked products. (Dadali, Demirhan and Ozbek, 2008). It is a rich source of iron 2.71 mg, magnesium 79 mg, and potassium 558 mg per 100g, and extraordinarily high in vitamins C 28 mg, vitamin E 2 mg, vitamin B6 0.195 mg and thiamine 0.078 mg, also it contain 9.6 g carbohydrates, 2.2 g dietary fiber, 2.9 g protein per 100 g (USDA, 2009). Spinach can be eaten raw as a salad, boiled, or baked into various dishes. It is low

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in calories and a good source of vitamin C, because of its high vitamin C content, dried spinach is also used in infant foods (Toledo, Ueda, Imahori, and Ayaki, 2003).

Spinach is a vegetable that rapidly perishes after harvest, which is consumed only in the product season. Like other leafy greens, spinach has high water content. Drying is one of the preservation methods that has the capability of extending the consumption period of spinach (Ozkan *et al.* 2007).

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 causes 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 is the one of the storage methods that has the capability of extending the consumption period of a sample. 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, flavour, 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 air sun drying and solar drying. But their disadvantages include inability to handle the large quantities and to achieve consistent quality standards, contamination problems, long drying times, low energy efficiency which is not desirable for the food industry. Hot-air drying is widely applied in food industry. Compared with natural drying methods, hot-air drying is less influenced by climatic conditions, reducing the drying cycle, and improving hygienic condition (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 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 has studied the drying behaviour 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 term, Weibull, Modified page, Two term exponential, Parabolic and Aproximation of diffusion among that Wang and Sing and Midilli *et al.* model was best fitted for grape leaves (Doymaz, 2012); Page model was best fitted for mint leaves (Park *et al.* 2002), Midilli *et al.* and Parabolic model was best fitted for bay laurel leaves (Doymaz, 2014); Modified page was best fitted for kale (Mwithiga and Olwal, 2005); Page model for chard leaves (Alibas, 2006); Page model for fever leaves (Sobukola and Dairo, 2016); Page model was best fitted for microwave dried spinach (Dadali *et al.* 2008) however the information for drying behaviour of convective dried spinach is very scares.

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

MATERIAL AND METHODS

The bunches of spinach (*Spinacia oleracia*) were procured from the local market of Roha (Maharashtra), India. The bunches were washed and leaves were separated from stalks.

Moisture content

The moisture content of spinach leaves was determined as per AOAC, 2010. Initial moisture content of spinach leaves was determined by the hot air oven method at 105°C ±1°C for 24 hours. The final weight of spinach leaves were recorded after 24 hours. The moisture content of the spinach leaves was determined by following 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

Convective hot air drying

Convective hot air drying of spinach was performed at Department of Post-harvest Engineering, Post-graduate Institute of Post-harvest Management, Killa-Roha. The drying was carried out in the convective hot air dryer (Make M/s. Aditi Associates, India; Model:ATD-124) having 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 81cm × 41cm × 3.4 cm. The leaves were spread on the tray in 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 location 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, moisture ratios with respect to time of spinach were recorded. Three replications were taken for each experiment.

Moisture ratio

The moisture ratio of spinach was calculated using 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)

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 spinach. Moisture ratio versus drying time (min) was also determined from the experimental data.

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

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 spinach 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 was determined for higher R^2 values and lower RMSE.

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

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).

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 (2.4) and lower value of RMSE values, the better is the equation fitting (goodness of the 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 (4);

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

Where,

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

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

N = is the number of observation, and

z = is the number of constant.

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

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:

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

Where,

H = is the half thickness of the slab m;

n = 1, 2, 3 … the number of terms taken into consideration.

$$1n(MR) = 1n\frac{8}{\pi^2} - \frac{\pi^2 D_{eff} t}{4L^2} \quad \ldots(7)$$

The diffusivities are typically determined by plotting the experimental drying data in the 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

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).

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

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):

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

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).

Preparation of powder

The dried leaves of spinach were grounded by mixer-grinder to average particle size 0.2 mm fine powder.

Physico chemical analysis and functional properties of spinach powder

1. Moisture content

The moisture content of spinach 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 dried spinach powder sample were recorded after 24 hours. The moisture content of the dried spinach powder was determined by following formula (Chakraverty, 1994). The each observation were recorded three times to get the replication;

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

2. Protein

Protein content in the spinach powder was determined by a micro-Kjeldahl distillation method (AOAC 2000). The dried powder sample of spinach at 45°C, 55°C and 65°C was digested by heating with concentrated sulphuric acid (H_2SO_4) in the presence of 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 appropriate factor (6.25). The observations were recorded three times to get the replication.

$$\%N = 1.4 \times \frac{\text{(mL HCL} - \text{mL blank)} \times \text{Conc.of HCL}}{\text{Weight of sample (g)}} \quad \ldots(12)$$

% Protein = % N × Factor (6.25)

3. Crude fat (%)

Crude fat of spinach powder dried at 45°C, 55°C and 65°C was estimated as crude ether extract of the dry material. The dry sample of spinach 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 desiccators and weighed. The fat content was expressed as g/100g (AOAC, 1995). The each experiment was repeated three times to get the replication.

Crude fat content (g/100g) =

$$\frac{\text{Weight of ether extracted}}{\text{Weight of sample taken}} \times 100 \quad \ldots(13)$$

4. Ash (%)

The tare weight of three silica dishes (7-8 cm dia) were noted and 5 g of the spinach powder sample dried at 45°C, 55°C and 65°C 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 hrs, in a muffle furnace. The dishes were cooled and weighed. The difference in weights represented the total ash content and was expressed as percentage, (Rangana, 1986). The each experiment was repeated three times to get the replication. The average reading of ash content was reported;

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

5. Crude fibre (%)

About 2–5 g of moisture and fat free sample of spinach powder dried at 45°C, 55°C and 65°C available in filter paper from fat extraction method (Ranganna, 1986) was weighed into a 500 ml beaker and a 200 ml of boiling 0.25 N sulphuric acid was added to the mixture and boiled for 30 min keeping the volume constant by addition of water at frequent intervals. The mixture was filtered through a muslin cloth and then transferred to the same beaker and 200 ml of boiling 0.313 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 crucible, dried overnight at 80⁰C to 100⁰C and weighed. The crucible was heated in muffle furnace at 525⁰C for 2 to 3 hrs, cooled and weighed again. The difference in the weights represented the weight of crude fibre, Rangana (1986). The each experiment was repeated three times to get the replication. The average reading of crude fibre was reported.

Crude Fiber (g/100g) =

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

6. Carbohydrates

Carbohydrate content of spinach powder dried at 45°C, 55°C 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 following equation (16);

$$\%\ \text{carbohydrate} = 100 - \%\ \text{protein} + \%\ \text{fat} + \%\ \text{fiber} + \%\ \text{ash} + \%\ \text{moisture content} \quad \ldots(16)$$

7. Colour

The dried leaves powder of spinach at 45°C, 55°C and 65°C was used to measure the colour value by using 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 spinach powder was taken in the glass cup, the cup was placed on the aperture of the instrument. The colour was recorded in terms of *L* = lightness (100) to darkness (0); *a* = Redness (+60) to Greenness (-60); *b* = yellowness (+60) to blueness (-60). The each observation were recorded three times for replication.

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 spinach at 45°C, 55°C and 65°C was placed in the test tube; while the timer was started, the tube is 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. The average reading was reported.

9. Water absorption capacity

Water absorption capacity of dried leaves powder of spinach at 45°C, 55°C 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 then cooled and weighed. The water absorption capacity was expressed as grams of water retained in the material. The each observation was recorded three times to get the replication.

RESULTS AND DISCUSSION

Convective hot air drying of spinach

Fig. 1 shows moisture content (db) % with respect to time (min) of spinach dried by convective hot air dryer.

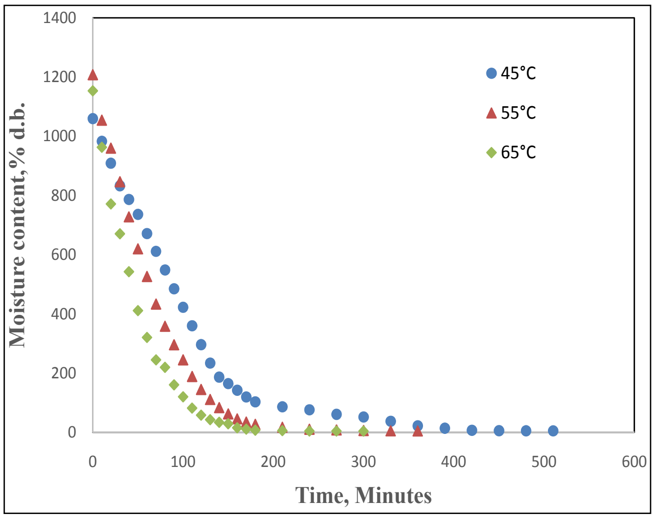

Fig. 1: Moisture content % (d.b.) versus time (min) of spinach leaves drying by convective hot air drying at different temperature

The spinach were dried from average initial moisture content of 1059.50% (db) to 5.110% (db) at 45°C; 1208.16% (db) to 4.749% (db) at 55°C; 1153.71% (db) to 4.286% (db) at 65°C respectively. It took around 8.5 h, 6 h and 5 h time to dry the product at 45°C, 55°C, and 65°C respectively.

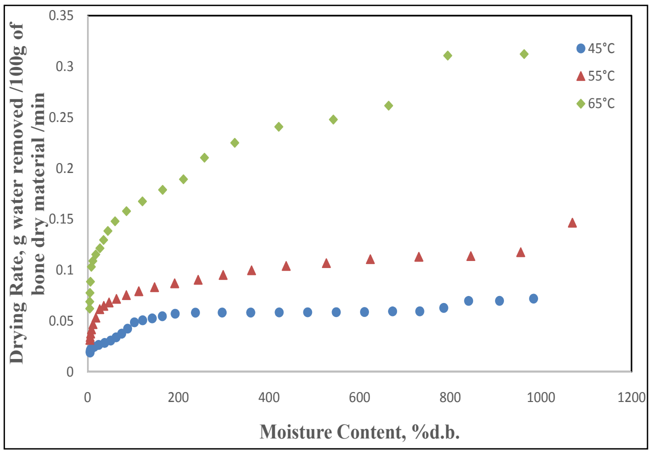

Fig. 2: Drying rate (g water removed/100 g of bone dry material/min) versus moisture content % (db) of spinach leaves dried by convective hot air drying at different drying temperature

Fig. 2 shows the drying rate (g water removed/100 g of bone dry material /min) with respect to moisture content % (db) of spinach dried by convective hot air drying at 45°C, 55°C, and 65°C. The initial drying rate of spinach was 0.071 g of water removed / 100 g of bone dry matter per minute and decreases up to the 0.018 g of water removed / 100 g of bone dry matter per minute at 45°C; 0.146 g of water removed / 100 g of bone dry matter per minute and decreases up to the 0.031 g of water removed / 100 g of bone dry matter per minute at 55°C; 0.312 g of water removed / 100 g of bone dry matter per minute and decreases up to the 0.062 g of water removed / 100 g of bone dry matter per minute at 65°C.

From Fig. 2 it was observed that the drying took place in falling rate period. As the temperature of drying increases from 45°C to 65°C the drying rate also increases. Moisture removal inside the spinach at 65°C was higher and faster than the other investigated temperature. Migration of surface moisture and evaporation rate from the surface to the air decreases with decrease of the moisture in the product. The shorter time of drying was observed at higher temperature thus increased drying rate (Zhu and Shen, 2014).

This increase in drying rate because of the increased heat transfer potential between the air and spinach which favours the evaporation of water from spinach. Similar observations reported in the literatures for parsley leaves, fever leaves and chard leaves by the Akpinar *et al*. (2008), Sobukola and Dairo , (2007) and 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 Aydin, (2009), Doymaz, (2009) and Doymaz, (2012) respectively.

Fig. 3 shows variation in moisture ratio with respect to time in minute. During the drying experiment moisture ratio decreases from 1 to 8.65×10^{-8}; 1 to 7.41×10^{-7}; and 1 to 9.42×10^{-7}; at the drying temperature of 45°C, 55°C and 65°C respectively. The similar trend was observed are in agreements with those reported by (Doymaz, 2009) for spinach leaves; (Alibas, 2006) for chard leaves (Mwithiga and Olwal, 2005) for kale.

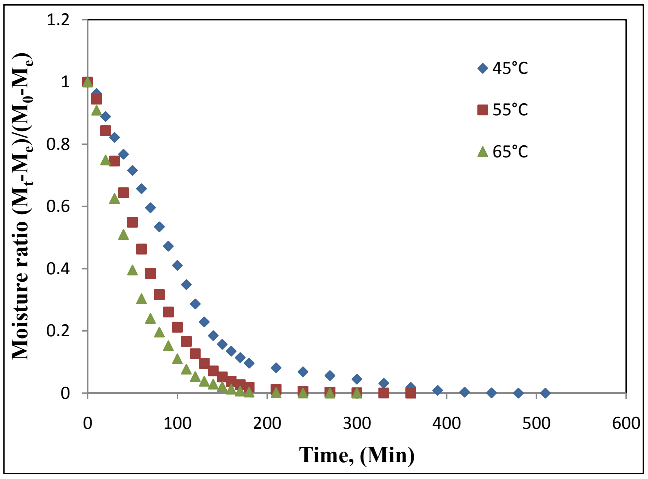

Fig. 3: Variation in moisture ratio with respect to time, (min) for spinach leaves during convective hot air drying at different temperature

Evaluation of thin layer-drying model of spinach dried by convective hot air drying.

The Table 1 (a), 1 (b) and 1 (c) shows the model parameters of various model fitted to the experimental data for Newton model, Page model, Henderson and Pabis, etc at 45°C, 55°C and 65°C by convective hot air drying of spinach 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 $R^2 \geq 0.998$; MSE $\leq 2.215\times10^{-4}$ and chi square (χ^2) $\geq 4.873\times10^{-3}$. Non- Linear regression analysis was done according to the three thin layer models for moisture ratio data. The Table 1 shows the statistical regression results of the different models, including the drying model coefficients and comparison criteria used to evaluate goodness of the fit including the R^2, χ^2 and RMSE of spinach at different temperature. In all cases R^2 values for the models were greater than 0.996 indicating a good fit. The model parameters for Page model were 'k' was 1.07×10^{-3}, 2.32×10^{-3}, and 5.57×10^{-3} at 45°C, 55°C and 65°C respectively. Value 'n' for Page model was 1.470, 1.417, and 1.303 for the 45°C, 55°C and 65°C respectively. The 'k' value increases with increase in temperature from 45°C to 65°C. 'n' value decreases with the increase in the temperature. Similar trends were observed for kale leaves (Mwithiga and Olwal, 2005).

Table 1: Model parameters, R^2, RMSE and Chi square (χ^2) values of spinach 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= 9.599×10^{-3}	0.981	3.280×10^{-3}	9.512×10^{-2}
2	Page	k=1.073×10^{-3} n = 1.470	0.996	4.527×10^{-4}	1.267×10^{-2}
3	Henderson and Pabis	a=1.103 k=1.06×10^{-2}	0.981	2.261×10^{-3}	6.332×10^{-2}

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 = 1.448×10^{-2}	0.988	2.763×10^{-3}	6.631×10^{-2}
2	Page	k = 2.324×10^{-3} n=1.417	0.999	2.104×10^{-5}	4.840×10^{-4}
3	Henderson and Pabis	a = 1.105 k = 1.590×10^{-2}	0.986	1.784×10^{-3}	4.105×10^{-2}

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

Sl. No.	Model name	Temperature 65°			
		Model Parameter	R^2	MSE	χ^2
1	Newton	k= 1.947×10^{-2}	0.993	1.490×10^{-2}	3.279×10^{-2}
2	Page	k=5.571×10^{-3} n=1.303	0.999	4.136×10^{-5}	8.686×10^{-4}

Effective moisture diffusivity of spinach dried by convective hot air drying

Fig. 4 shows Ln (MR) versus time (minute) for convective hot air drying of spinach 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 line. Effective diffusivity

(D_{eff}) at time for spinach which was calculated by Eq (7). Table 2 shows the effective diffusivity of spinach dried at 45°C, 55°C and 65°C. The diffusivity values were in the range of 1.775×10^{-9} to 3.606×10^{-9} for all the temperature. As the temperature increases the diffusivity value increases from 1.775×10^{-9}, 2.663×10^{-9} and 3.606×10^{-9} m²/s at 45°C, 55°C and 65°C respectively. The effective diffusivity used to explain the mechanism of moisture movement during drying and complexity of the process (Kashaninejad *et al.* 2007; Falade and Solademi, 2010). Generally, effective moisture diffusivity increased with increased air temperature (Falade and Solademi, 2010).

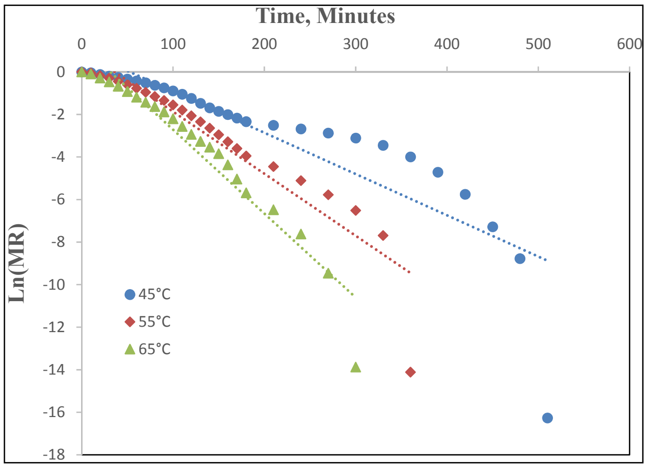

Fig. 4: Ln(MR) versus time, minutes for effective diffusivity for convective hot air dried spinach leaves at varied temperature

It was observed that D_{eff} values increased greatly with increasing drying temperature. When samples are dried at higher temperature, increased heating energy would increase the activity of the water molecules leading to higher moisture diffusivity (Xiao *et al*. 2010). The values obtained of effective diffusivity from this study was 1.775×10^{-9}, 2.663×10^{-9} and 3.606×10^{-9} m²/s during the drying temperature of 45°C, 55°C and 65°C respectively. The values of D_{eff} obtained from this study lie within in general range 10^{-12}–10^{-8} m²/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 ranged from 16.590×10^{-10} to1.927×10^{-9}m²/s. (Doymaz, 2009); 0.295– 3.60×10^{-9} m²/s for olive leaves (Nourhéne *et al.* 2008); 1.021–10.44 $\times 10^{-9}$ m²/s for Mexican tea leaves (Kane *et al.* 2008), 1.49–5.59 $\times 10^{-10}$ m²/s for kale (Mwithiga and Olwal, 2005) and 1.744–4.992 $\times 10^{-9}$ m²/s for neetle and mint leaves (Kaya and Aydin, 2009).

Activation energy for spinach dried by convective hot air drying

Fig. 5 shows the Ln(D_{eff}) vs $1/T_{abs}$ for dried spinach 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 showed straight line in the range of air temperature studied. The activation energy E_a for moisture diffusion calculated from the slope of straight lines graphs are given in Table (2). The activation energy for moisture diffusion was found to be 31.677 kJ/mole. The energy of activation (E_a) are reported in the literature, for convective hot air drying of spinach was 34.35 kJ/mole (Doymaz, 2009), also E_a for spinach, it is lower than the activation energy of kale drying is 36.11 kJ/mole (Mwithiga and Olwal, 2005); mint leaves was 82.928 kJ/mole (Park *et al.*, 2002) and fever leaves drying is 80.78kJ/mol (Sobukola and Dairo, 2007). The activation energy is also nearer to the E_a of bay laurel leaves that is 36.48 kJ/mole (Doymaz, 2014).

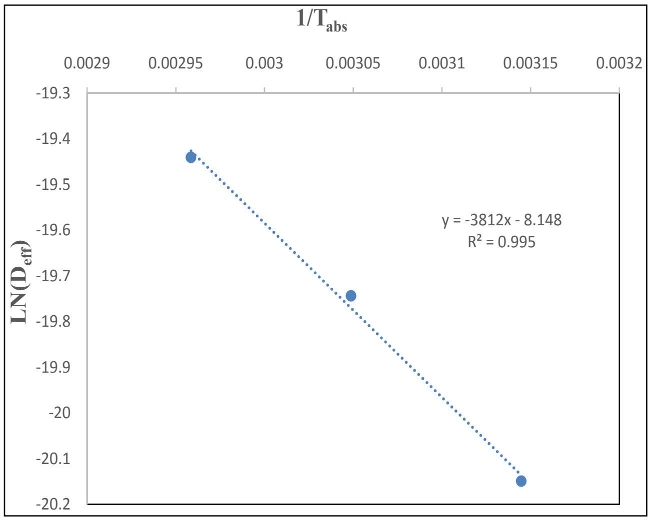

Fig. 5: Ln(D_{eff}) vs $1/T_{abs}$ for drying of spinach leaves dried by convective hot air drying method at different temperatures

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

Temperature, °C	D_{eff} (m²/s)	Ea (kJ/mole)
45°C	1.775×10^{-9}	
55°C	2.663×10^{-9}	31.677
65°C	3.606×10^{-9}	

The results indicated a linear relationship between Ln(D_{eff}) and (1/T_{abs}) as plotted in Fig. 5 for spinach dried by convective drying at 45°C, 55°C and 65°C. The diffusivity constant or pre- exponential factor of Arrhenius equation (D_0) and activation of energy (E_a) calculated from the linear regression are 2.89×10^{-4} m^2/s and 31.677 kJ/mol for spinach. The relationship between D_{eff} and activation energy of spinach leaves are given in Eq. (16);

$$D_{eff} = \left(2.89\times10^{-4}\right)\exp.\left(-\frac{31.677}{R\left(T+273.15\right)}\right) \qquad \ldots(16)$$

Physico-chemical and functional properties of dried spinach powder

Table 3 shows the physico-chemical properties i.e. moisture content, protein, fat, ash, fiber, carbohydrate, colour L, a, b water absorption capacity, wettability, of dried spinach powder at 45, 55 and 65˚C.

1. Moisture

Table 3 (a) shows the moisture content for spinach powder. Moisture content varied for spinach powder ranged was 6.67±0.02 %(wb), 6.47±0.05 %(wb), 6.22±0.10 % (wb), at 45˚C, 55˚C and 65˚C respectively. Highest moisture content for spinach observes at 45˚C drying temperature. The moisture of spinach was significant at $p\leq0.01$. Similar trend was observed in spinach powder moisture content decreases with increase in temperature from 50˚C to 80˚C from 4.86±0.03 to 1.71±0.10 (Ankita and Prasad, 2013) hot air oven dried moringa leaves shows moisture content of 6 % (Joshi and Mehta, 2010).

2. Protein

Table 3 (b) shows the (%) protein content for spinach powder. Protein content varied for spinach powder ranged was 10.73±0.02%, 10.33±0.01% and 10.10±0.01% at 45˚C, 55˚C and 65˚C respectively. Highest protein content observed at 45˚C of spinach powder. The protein content decreases with increase in temperature from 45˚C to 65˚C. The decrease in protein content w. r. t. increase in temperature was significant at $p\leq0.01$. The protein content for shade dried spinach powder was 19.10% reported by Kavitha and Ramdas, 2013. Similar decreasing trend

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

Sl. No.	Chemical constituent	Spinach			SE (@p≤0.01)	CD (@p≤0.01)
		45°C	55°C	65°C		
(a)	Moisture % (w.b.)	6.67±0.02	6.47±0.05	6. 22±0.10	0.039	0.135
(b)	Protein	10.73±0.02	10.33±0.01	10.10±0.01	0.007	0.025
(c)	Fat	3.04±0.01	3.11±0.01	3.14±0.03	0.011	0.036
(d)	Ash	6.70±0.01	6.40±0.02	6. 31±0.02	0.009	0.031
(e)	Fiber	14.33±0.03	13.03±0.03	11.21±0.13	0.044	0.151
(f)	Carbohydrate	58.53±0.04	60.66±0.05	63.03±0.21	0.072	0.251
(g)	Colour L	54.03±0.02	54.30±0.87	51.39±0.72	0.376	1.301
(h)	Colour a	18.14±0.03	19.68±0.23	17.92±0.17	0.096	0.334
(i)	Colour b	28.44±0.02	30.50±0.52	29.82±0.29	0.200	0.692
(J)	Wettability (sec)	82±5.70	51±0.55	42±2.34	2.063	7.140
(k)	Water absorption capacity (g/ml)	7.57±0.21	8.59±0.01	8.77±0.03	0.070	0.242

of protein content was observed in hot air dried moringa leaves it has high 23.75 % at 50°C while it is 16 % at 70°C. (Kannan and Thahaaseen, 2016)

3. Fat

Table 3 (c) shows the (%) fat content for spinach powder. Fat content varied for spinach powder from 3.04±0.01 (%), 3.11±0.01 (%) and 3.14±0.03 (%) at 45˚C, 55˚C and 65˚C respectively. Highest fat content observed at 65˚C of spinach powder. The increase in fat was significant at p≤0.01. The fat content observed in shade dried spinach powder was 7.11 % reported by Kavitha and Ramdas, 2013. Joshi and Mehta, 2010 reported that the fat content of oven dried moringa leaf powder was 7.01%.

4. Ash

Table 3 (d) shows the ash content for spinach powder. Ash content varied for spinach powder ranged was 6.70±0.01 (%), 6.40±0.02 (%) and 6.31±0.02 (%) at 45˚C, 55˚C and 65˚C respectively. Highest ash content observed in 45˚C of spinach powder, while lowest ash content was observed at 65⁰C.The decrease in ash was significant at p≤0.01. Kavitha and Ramdas, 2013 reported that ash content in the shade dried spinach leaf powder samples was 5.57%.

5. Fiber

Table 3 (e) shows the fiber content for spinach powder. Fiber content varied for spinach powder ranged was 14.33±0.03 (%), 13.03±0.03 (%) and 11.21±0.03 (%) at 45˚C, 55˚C and 65˚C respectively. Highest fiber content observes at 45˚C drying temperature. The decrease in fiber content with increase in temperature was significant at p≤0.01. Kavitha and Ramdas, 2013 reported the fiber 7.11% in shade dried spinach powder. Similar results was observed by Joshi and Mehta, 2010 the fibre content of oven dried moringa leaf powder was 11.8 %.

6. Carbohydrate

Table 3 (f) shows the carbohydrate content for spinach powder. Carbohydrate content varied for spinach powder ranged was 58.53±0.04 (%), 60.66±0.05 (%) and 63.03±0.21 (%) at 45˚C, 55˚C and 65˚C respectively. Highest carbohydrate content was observed at 65˚C drying temperature. The increase in carbohydrate content with increase in temperature was significant at p≤0.01. Kavitha and Ramdas, 2013 observed the 41.49% carbohydrate in dried spinach powder. Joshi and Mehta, 2010 reported that the carbohydrate content of oven dried moringa leaf powder was 28.38 %

7. Colour

Table 3 (g) shows the colour 'L' for spinach powder dried at 45, 55 and 65˚C. L value for 45˚C, 55˚C and 65˚C was 54.03±0.02, 54.30±0.87 and 51.39±0.72 respectively. The change in colour 'L' value is significant at p≤0.05.

Table 3 (h) shows colour 'a' value for 45˚C, 55˚C and 65˚C was 18.14±0.03, 19.68±0.23 and 17.92±0.17 respectively The change in colour 'a' value is significant at p≤0.05.

Table (i) shows colour 'b' value for 45˚C, 55˚C and 65˚C was 28.44±0.02, 30.50±0.52 and 29.82±0.29 respectively, the change in colour 'b' value is significant at p≤0.05.

The highest L, a and b values were observed at 55˚C, Alibas, 2006 reported that the chard leaves colour increased with increase in temperature. The darkness were reported to increase with increased temperature observed in spinach (Ankita and Prasad, 2013).

8. Wettability

Table 3 (j) shows the wettability for spinach powder. Wettability varied for spinach powder ranged from 82.00±5.70 sec, 51±0.55 and 42±2.34 sec at drying temperature 45˚C, 55˚C and 65˚C respectively. Highest wettability observed at drying temperature of 45˚C of spinach powder. The change in wettability at varied temperature of drying was significant at p≤0.01. Similar results was observed by Gulia *et al.* (2010) who reported that the wettability of Aloe vera powder ranged was 35 to 37(sec) at 50, 60,70 and 80˚C respectively.

9. Water absorption capacity

Table 3 (k) shows the water absorption capacity for spinach powder. Water absorption capacity varied for spinach powder ranged was 7.57±0.21 (g/ml), 8.59±0.01 (g/ml) and 8.77±0.03 (g/ml) respectively. Highest water absorption capacity observed at 65˚C of spinach powder. The increase in water absorption capacity was significant at p≤0.01. The results are in general agreement with the spinach leaves powder ranged from 2.422±0.019-2.588±0.09 g/g (Ankita and Prasad, 2013). Olua *et al.* (2015) reported the water absorption capacity of 1.200±0.00 (g/ml) for cashew apple powder respectively.

CONCLUSION

The drying of spinach leaves occurred in the falling rate period. It took around 8.5 h, 6 h and 5 h time to dry the product from 1059.50% (db) to 5.110% (db), 1208.16% to 4.749% (db), and 1153.71% to 4.286% (db). Experimental data of moisture ratio with respect to time of spinach drying were fitted the Page model which betterly describes than the other models i.e. Henderson and Pabis and Newton's model. The effective moisture diffusivity varied from 1.77578 $\times 10^{-9}$, 2.66367 $\times 10^{-9}$ and 3.60649 $\times 10^{-9}$ m^2/s over the temperature range studied, and it increases with the increase of the air temperature. The activation energy of the spinach leaves was found as 31.677 kJ/mol. The protein, ash and fiber content decreased from 10.73 to 10.10 %, 6.70 to 6.31 % and 14.33 to 11.21% with increase in temperature, the fat is increased from 3.04 to 3.14 % with increased temperature, wettabilty is decreased from 82 (sec) to 42 (sec) and water absorption capacity is increased from 7.57 (g/ml) to 8.77(g/ml) with increasing temperature from 45°C to 65°C The better nutritional and functional properties have been observed at 45°C.

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