Study of Drying Characteristics of Moringa Leaves

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Abstract

To simulate the drying process and to design the equipment needed for drying of Moringa leaves, study of its modeling is important. During the experiment, different mathematical equations were used to best fit the model describing the drying behavior of blanched and un-blanched Moringa leaves at 40^0C, 50^0C & 60^0C. Effective moisture diffusivity & activation energy of Moringa leaves were also determined. It was observed that, Pelag's model was the best fit for drying of blanched Moringa leaves at 50^0C (R^2 ≥0.999). For blanched Moringa leaves sample, effective moisture diffusivity varied from 2.85 x 10^{-7} to 7.57 x 10^{-7}, whereas its activation energy for drying was observed as 1821.76 KJ/mol. This knowledge can be useful for designing/modeling mass transfer processes of Moringa leaves during its storage.

Keywords: Moringa, blanching, Pelage model, effective moisture diffusivity, activation energy

Introduction

Food and agricultural materials should be dried to inhibit the microbial spoilage and enzymatic degradation owing to their moisture and biologically active contents. Drying of natural products enhances the extraction of high added value compounds. India is blessed with an array of leafy vegetables. Green Leafy Vegetables like methi, mint, coriander, curry leaves, amaranthus and drumstick leaves represent an excellent component of the habitual diet in the tropical and temperate countries. This group of foods are rich source of vitamins like vitamin-A in the form of β-carotene, ascorbic acid, riboflavin, folic acid; minerals like calcium, iron, potassium, sodium and phosphorous.

Moringa Oleifera is the most widely cultivated species of the genus Moringa. India is the largest producer of Moringa, with an annual production of 1.1 to 1.3 million tons of tender fruits from an area of 380 km^2 [Jethava *et al.,* 2015]. *Moringa Oleifera*is grown largely in tropical and sub-tropical areas. Moringa can be described as miracle tree as its leaves are an abundant indigenous source of digestible proteins, vitamins, mineral and carbohydrates that are necessary for human beings of all ages. It was estimated that, almost three hundred diseases can be cured by taking Moringa leaves along with hundreds of other health benefits. It also contains more than 90 nutrients, different antioxidants and all the eight essential amino acids [Ali *et al.,* 2014].

Drying is the first and critical step in food processing containing both energy and mass transport phenomena. Therefore, modeling studies should be carried out in order to simulate and design the equipment and processes. Even though there are numerous studies on the drying of food and agricultural products, information on biologically active materials whose drying behaviors are described by several empirical models is scarce. [Elhussein *et.al.,* 2018]. A knowledge of effective moisture diffusivity is necessary for designing and modeling mass transfer process such as dehydration, adsorption and desorption of moisture during storage. To predict the moisture transfer during the falling rate drying period, mathematical models have been proposed using Fick's diffusion as the basis to describe the moisture transport process. Moisture transfer during drying is controlled by internal diffusion. The effective moisture diffusivity represents the conductive term of all moisture transfer mechanisms. This parameter is usually determined from experimental drying curves.

The diffusion coefficient of a food product is a material property and its value depends upon the conditions within the material. Effective moisture diffusivity describes all possible mechanisms of moisture movement within the product, such as liquid diffusion, vapor diffusion, surface diffusion, capillary flow and hydrodynamic flow. Moisture transport which involves diffusion of moisture in solid foods is complex process. A knowledge of effective moisture diffusivity is necessary for designing and modeling mass transfer processes such as dehydration, adsorption and desorption of moisture during storage [Rafiee *et al.*, 2010]. In the view these, the present study was undertaken with following objectives.

1) To study the drying behavior of blanched and un-blanched Moringa leaves at 40^0C, 50^0C & 60^0C.
2) To fit the best mathematical model for drying of Moringa leaves.
3) To determine the effective moisture diffusivity and activation energy for drying of Moringa leaves.

Methods

Freshly harvested Moringa leaves were collected & sorted. These sorted leaves were taken for the experimentation. The initial and intermittent moisture content (% d.b.) of Moringa leaves were determined by standard AOAC (2000) method. The total sample was divided into two parts, one part of which was treated with blanching process & other part was kept un-blanched. Blanching was carried out by treating the Moringa leaves with hot water for 1–10 min at 75–95^0C. After blanching, the leaves were kept in cold water for 5 min. for cooling & then kept in an open air for half an hour. Both treated & untreated samples were then used for process of drying in tray dryer at 40^0C, 50^0C & 60^0C. The drying behavior of treated and untreated Moringa leaves was determined in terms of drying curve. Mathematical equations representing the drying behavior of Moringa leaves were then determined by using Peleg, Lewis, Page, Modified Page & Henderson - Pabis Model. The statistical analysis of these models was done with the help of correlation analysis.

During a diffusion process at constant temperature, it was assumed that the process follows Fick's second law of moisture diffusion, hence the effective diffusivity of Moringa leaves was calculated by using equation (1) (Rafiee *et. al.*, 2010). The term activation energy in Arrhenius equation is regarded as best experimentally determined parameter which indicates the sensitivity of reaction rate to temperature, which was determined by using equation (2) (Elhussei *et. al.*, 2018). Arrhenius equation was used to describe the temperature dependence of effective diffusivity, whereas activation energy was determined from the slope of Arrhenius plot of ln (D) verses 1/T. The activation energy was calculated by multiplying the slope coefficient (Ea/R) by universal gas constant (8.314 kJ/mol/k). Using above equation the value of activation energy was calculated.

$$MR = \frac{M}{Mo} = \frac{8}{\pi^2}\sum_{n=1}^{\infty}.\frac{1}{(2n-1)^2}\, e\left(\frac{(2n-1)^2\pi^2 Dt}{4L^2}\right) \qquad \text{-----------(1)}$$

Where,

Mo = Initial moisture content (kg water/ kg dry solid)

MR = Moisture ratio

M = Moisture content at any time (kg water/ kg dry matter)

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

t = Drying time (s)

D = Effective moisture diffusivity (m^2/s)

L = Drying thickness (m)

$$\frac{1}{K1} = A\, e(-Ea/RT) \qquad \text{--------------} \ (2)$$

Where,

A = constant (frequency factor) ($h\%^{-1}$)

Ea = activation energy (kJ/mol)

R= universal gas constant (80314 kJ/mol/K)

T= absolute temperature

Results

Initial moisture content (% d.b.) of blanched Moringa leaves was found to 85.18 whereas that of un-blanched Moringa leaves was found to 114.28. Drying behavior of blanched and un-blanched sample of Moringa leaves showed the inverse relation between dying time and drying temperature. Also it was observed that moisture removal of un-blanched sample was greater than that of blanched sample whereas the rate of drying decreased continuously throughout the drying period. Constant rate period was observed to be absent during drying of Moringa leaves as it took place in falling rate period.

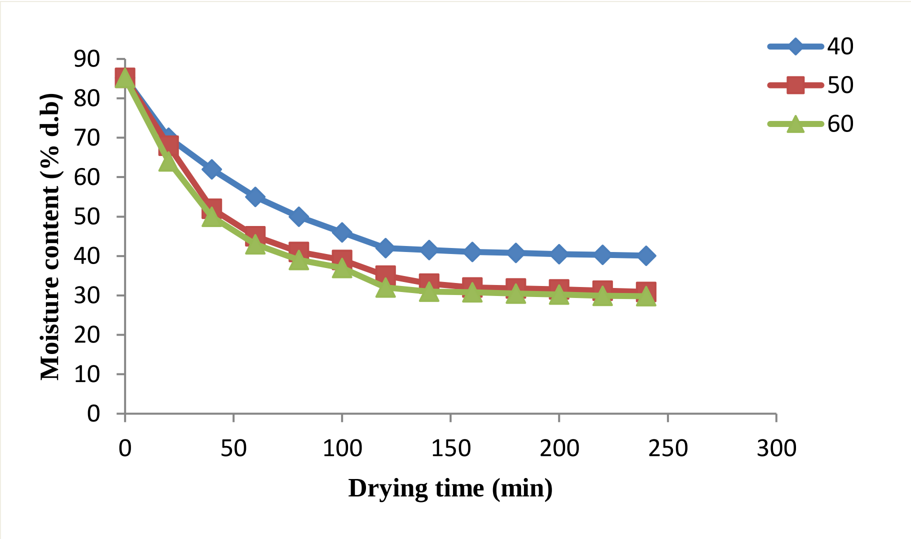

Fig.1. Drying curve for blanched Moringa leaves sample

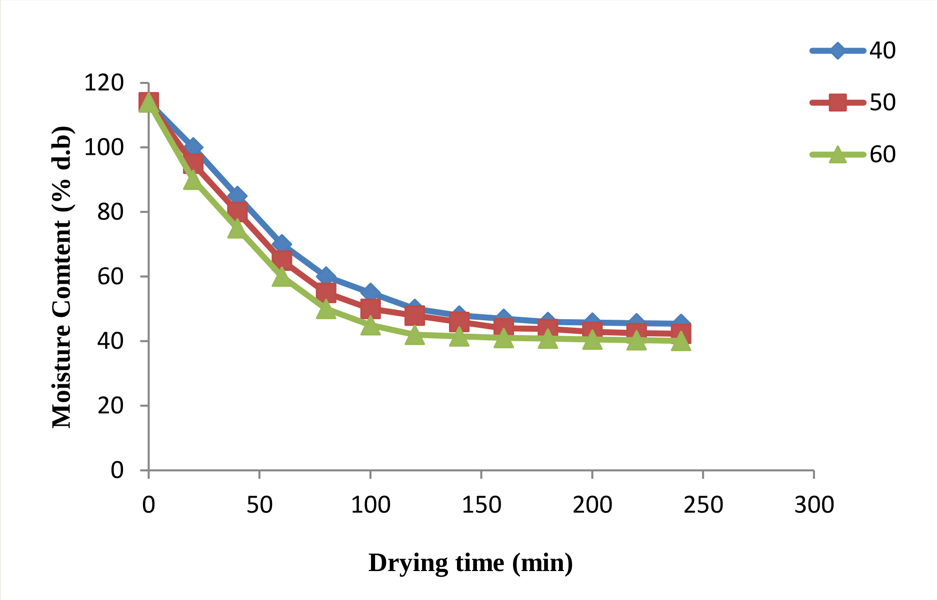

Fig.2. Drying curve for un-blanched Moringa leaves sample

Peleg Equation: This equation can be employed to predict moisture successfully, or at least estimate, from the experimental data obtained in test of relatively short duration (Erbay *et. al.*, 2009). The original form of Peleg equation is given as

$$M = Mo + \frac{t}{(k1+k2t)}$$

Where,

M = Moisture content (% dry basis)

t = Drying time

k1 = Peleg's rate constant (time $\%^{-1}$db)

k2 = Peleg's capacity constant ($\%^{-1}$db)

Table 2. Peleg's equation constants for drying of Moringa leaves

Sample	**Temperature (°C)**	**k1(hr%db^{-1})**	**k2(hr.%db^{-1})**	**R^2**
Blanched Moringa Leaves	40	10.80	0.08	0.973
	50	24.06	0.18	0.999
	60	37.01	0.42	0.975
Un-blanched Moringa Leaves	40	1.99	0.01	0.699
	50	0.53	0.01	0.987
	60	0.21	0.01	0.990

Lewis Equation: This equation is analogous with Newton's law of cooling, so many investigators named this equation as Newton's equation (Erbay *et. al.*, 2009). The Lewis equation is given as

$$MR = \frac{(Mt - Me)}{(Mi - Me)} = \exp(-kt)$$

Where,

Mi = Initial moisture content (% dry basis)

Mt = Mean moisture content at time (% dry basis)

Me = Equilibrium moisture content (% dry basis)

K = Drying constant (/sec)

t = Drying time

Table 3. Lewis equation constants for drying of Moringa leaves

Sample	Temperature (°C)	k	R^2
Blanched Moringa Leaves	40	76.19	0.971
	50	63.71	0.966
	60	49.35	0.935
Un-blanched Moringa Leaves	40	108.10	0.975
	50	96.76	0.959
	60	80.73	0.956

Page Equation: Page modified the Lewis equation to get more accurate equation by adding a dimensionless empirical constant (n) to the mathematical modelling of drying (Erbay *et. al.*, 2009).

$$MR = \frac{(Mt - Me)}{(Mi - Me)} = \exp(-kt^n)$$

Where,

Mi = Initial moisture content (% dry basis)

Mt = Mean moisture content at time (% dry basis)

Me = Equilibrium moisture content (% dry basis)

K = Drying constant (/sec)

t = Drying time

n = Model constant (dimensionless)

Table 4. Page equation constants for drying of Moringa leaves

Sample	Temperature (°C)	k	R^2
Blanched Moringa Leaves	40	- 1.51	0.996
	50	- 1.63	0.943
	60	- 2.32	0.984
Un-blanched Moringa Leaves	40	- 4.66	0.946
	50	- 3.44	0.970
	60	- 2.43	0.950

Henderson and Pabis Equation: Henderson and Pabis improved an equation for drying by using Fick's law of diffusion and applied the new equation on drying.

$$MR = \frac{(Mt-Me)}{(Mi-Me)} = a \exp(-kt)$$

Where,

Mi = Initial moisture content (% dry basis)

Mt = Mean moisture content at time (% dry basis)

Me = Equilibrium moisture content (% dry basis)

K = Drying constant (/sec)

t = Drying time

a = Model constant (dimensionless)

Table 5. Handerson and Pebis equation constants for drying of Moringa leaves

Sample	Temperature (°C)	k	a	R^2
Blanched Moringa Leaves	40	- 0.70	- 0.03	0.992
	50	- 0.56	- 0.03	0.963
	60	- 0.19	- 0.05	0.990
Un-blanched Moringa Leaves	40	0.37	- 0.03	0.912
	50	0.11	- 0.04	0.972
	60	- 0.16	- 0.04	0.961

Modified Page Equation: Diamanté and Munro used modified form of Page equation to describe the drying of tuber crop. This is generally known as the Modified Page equation (Erbay *et. al.*, 2009).

$$MR = \frac{(Mt-Me)}{(Mi-Me)} = \exp -k(t/l^2)n$$

Where,

Mi = Initial moisture content (% dry basis)

Mt = Mean moisture content at time (% dry basis)

Me = Equilibrium moisture content (% dry basis)

K = Drying constant (/sec)

t = Drying time

l= Empirical constant (dimensionless)

Table 6. Modified page equation constants for drying of Moringa leaves

Sample	Temperature (°C)	k	R^2
Blanched Moringa Leaves	40	- 1.16	0.987
	50	- 1.33	0.992
	60	- 2.34	0.973
Un-blanched Moringa Leaves	40	- 5.37	0.944
	50	- 4.39	0.980
	60	- 3.12	0.990

Effective Moisture diffusivity (D): It was observed that, the effective moisture diffusivity during drying of Moringa leaves at temperature range 40°C to 60°C for blanched sample varied from 2.85×10^{-7} to 7.57×10^{-7} m^2/s, whereas for un-blanched sample it varied from 1.45×10^{-8} to 6.37×10^{-8} m^2/s.

Activation Energy (E_a): Activation energy for blanched sample of Moringa leaves from intercept and slope (Ea/R) was found to be 1821.76 kJ/mol, whereas that of for un-blanched sample of Moringa leaves was found to be 1385.36 kJ/mol.

Table 7. Values of activation energy and constant A

Sample	Slope (Ea/R)	Intercept (ln A)	R^2	Activation Energy (Ea) (kJ/mol)
Blanched Moringa Leaves	219.12	10.611	0.9986	1821.76
Un-blanched Moringa Leaves	166.63	13.805	0.9604	1385.86

Conclusions

1. Out of different models discussed, Peleg's mathematical model was observed to be the best fit for describing the drying behavior of blanched Moringa leaves at 50°C ($R^2 = 0.999$).
2. Thus knowledge of effective moisture diffusivity and activation energy of Moringa leaves is useful for designing/modeling of its mass transfer processes (such as dehydration, adsorption and desorption) during its storage.

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