International Journal of Food and Fermentation Technology
Citation: *Int. J. Food Ferment. Technol.*, **16**(01): 25-40, June 2026
DOI: 10.30954/2277-9396.01.2026.3

ASSOCIATION FOR AGRICULTURE ENVIRONMENT AND BIOTECHNOLOGY

RESEARCH PAPER

Effect of Drying Temperatures on Physicochemical Properties of Moringa Pod Pulp Powder

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Paper No.: 346 **Received:** 11-04-2026 **Revised:** 10-05-2026 **Accepted:** 22-05-2026

ABSTRACT

The present project was undertaken to study preliminary aspect of drying of *Moringa oleifera* pods. The aim was to utilize *moringa* pod pulp for commercial value added product. The drying of *moringa* pod pulp was investigated by convective hot air drying method at different temperature 40°C. 50°C and 60°C. Three drying model i.e., Newton, Henderson and Page were fitted to the experimental data on moisture ratio with respect to time. Page model best fitted with $r^2 \geq 0.9691$; MSE ≤ 0.003 and chi square (χ^2) ≥ 0.0009. Effective diffusivity values were 3.34×10^{-8}, 6.795×10^{-8} and 8.36×10^{-8} at 40°C, 50°C and 60°C respectively. The activation energy (E_A) for moisture diffusion was found 32.927 kJ/mole, The effect of quality parameter i.e. moisture, ash, fat, protein, carbohydrate, vit 'c', phenolic content, flavonoid, DPPH, beta carotene on fresh *moringa* pod pulp and dried *moringa* pod pulp powder at 40°C, 50°C and 60°C respectively were also determined and discussed. Better retention of quality paraeters were observed at 40°C Moisture 4.145, Ash 6.500, Fat 3.363, Protein 9.490, Carbohydrate 75.453, vit 'c' 187.5, beta carotene 16.185, Phenol 2888, Flavonoid 518.0, DPPH 82.743 respectively. The drying kinetics were studied using different drying model, and the page model was found to best describe the drying behaviour of *moringa* pod pulp, showing the highest coefficient of determination and better fit among the tested model.

Keywords: *Moringa oleifera,* phenolic content, flavonoid, capsule, drumstick

Moringa is traditionally referred to as the miracle of the tree or the tree of life. Moringa trees are commonly planted in backyards in the Philippines, Thailand, and India, and their young pods and leaves are available in local markets as soup ingredients (Radha *et al.* 2015). *Moringa oleifera* is a short-lived, fast-growing crop that can withstand drought. The tree, which is widely used in South and Southeast Asia and is native to northern India, Moringa is a member of the family *Moringaceae.* Common names include *moringa*, malunggay (as recognized in Asian maritime or archipelagic locations), and horseradish tree (because the roots taste like horseradish). due to the tall, thin, triangular seed pods that resemble the musical instrument (Anasari *et al.* 2021).

Moringa is a widely used medicinal plant in India and other countries, *Moringa oleifera* pods have received relatively less attention than its leaves, which have been the focus of extensive. Moringa's fruit, or "pod," is a 10–100 cm long, three-valved capsule that is green while it is young and brown when it is old. It is also referred to as a drumstick. With significant quantities of fiber (~46.78%) and protein (~20.66%), as well as important vitamins and amino acids, immature pods are very healthy. While mature pods are usually fried

How to cite this article: Shinde, R.S. and Swami, S.B. (2026). Effect of Drying Temperatures on Physicochemical Properties of Moringa Pod Pulp Powder. *Int. J. Food Ferment. Technol.*, **16**(01): 25-40.

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

and have a peanut-like flavour, they can be eaten raw or cooked (Shivanna *et al.* 2024).

Moringa is valued for both pod and leaves, through they differ notably in taste and nutritional composition. Immature Moringa pod are widely consumed as vegetable and appreciated for their mild, slightly sweet flavour and crisp texture, often compared to leaves (Anwar *et al.* 2007). In contrast, Moringa leaves are considered highly nutrient- dense, through their taste is quite distinct, often described as slightly bitter, astringent and grassy. Which may limit their direct acceptability in diets (Gopalakrishna *et al.* 2016). Moreover, one of the key limitations of using Moringa leaves in everyday diets in their naturally bitter and astringent taste, which can reduce consumer acceptability. This sensory drawback is often overcook in diversification strategies, even through it plays a crucial role in determining whether people are willing to include Moringa based foods in their daily meals (Grosshagauer *et al.* 2021).

Due to this exceptional nutritional profile, *Moringa* is increasingly being explored as a functional food ingredient in the development of value added products such as powders, soups and food. However, differences in sensory attributes between pods and leaves highlight the importance of selecting appropriate plant parts and processing methods to enhance both nutritional quality and consumer acceptability (Gopalakrishna *et al.* 2016).

Production of the *Moringa* in the world, India is the largest producer of *Moringa*, cultivating the crop over approximately 38,000 ha and producing about 1.1-1.3million tonnes of pods annually. Studies indicate that the yield of *Moringa* leaves can reach up to 650 tonnes per ha, although it varies considerably depending on factors such as plant spacing, climatic conditions, and the variety grown. In comparison, perennial *Moringa* trees require nearly one year to attain full growth before harvest and generally produce few pods during the initial two years of cultivation that annual varieties.

Due to the high nutritional value there is a need to design and develop strategies to explore and utilize the benefits of this miracle. Fresh *moringa* pod pulp contains high moisture content, which makes it highly perishable and susceptible to microbial spoilage, enzymatic degradation, and quality deterioration during storage. Therefore preservation techniques are essential to extend its shelf life and reduce post harvest losses. Drying is one of the oldest and most effective methods of food preservation in which moisture is removed from the food material by the application of heat and airflow to inhibit the microbial growth and enzymatic activity (Chakravarty, 1994). Drying not only improves storage stability but also reduces the weight and volume of the product, thereby facilitating easy handling, transport, and packaging.

Looking to the health prospect of the *moringa* pulp is market demand, there is a great scope for the value addition of *moringa* pulp in term of development of value added products. There is a gap between raw produce and market requirement of this miracle tree. The present study include determining physicochemical characteristics of *moringa* pod pulp. Blanching is pretreatment carried out for fruits and vegetables before polyphenol oxidase need to be inactivated through blanching treatment for better product quality degradation enzyme i.e value addition as well as for better storage quality (Ameen ravani *et al.* 2020).

The present study investigations could be the optimization of drying temperatures, drying models and effect of pre-treatment of blanching for peroxidase enzyme inactivation as well as maximum retention of pulp during blanching. During the drying process, moisture present in *moringa* pod pulp evaporates, resulting in physical and chemical changes in the material. Reduction in moisture content helps in improving shelf stability and converting the pulp into value added products such as soup premixes, nutraceuticals, and instant foods (Shah *et al.* 2016).

In recent years, increasing consumer demand for healthy and functional food has encouraged research on the processing and preservation of *moringa* based products. Studies on drying characteristics

and mathematical modelling are important for understanding moisture removal behaviour and selecting suitable drying conditions for understanding the moisture removal behaviour and selecting suitable drying conditions for industrial applications. Thin layer drying models such as the page model have been widely used to describe drying behaviour of agricultural materials due to their better prediction accuracy (Doymaz, 2004). Hence, the present work was undertaken to study the drying characteristics of *moringa* pod pulp under different drying temperatures and to evaluate the effect of drying on nutritional composition, antioxidant activity and quality attribute for the development of stable and nutritious food products.

MATERIALS AND METHODS

Raw Material

Fresh *moringa* (*Moringa oleifera*) pods were procured from the local market of kolad. The pods were washed thoroughly under running tap water to remove dirt and foreign materials.

Preparation of *Moringa* Pod Pulp

Fresh *moringa* pods were washed thoroughly and cut into approximately 5 cm uniform pieces. The pieces were then manually peeled to remove the outer skin. The peeled pod pieces were blanched in hot water at 60°C for 3 minutes using a pod to water ratio 1:5(w/v). After blanching, the pulp was carefully separated from the pods using a stainless steel knife. The extracted pulp was collected and used for further drying process.

Moisture Content

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

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

Where,

W_1 = weight of sample before drying, g

W_2 = weight of sample after drying, g

Convective Hot air Drying Process

The convective hot drying of *Moringa* pod pulp was carried out at Department of Post Harvest Engineering, Post Harvest Graduate Institute of Post Harvest Management, Killa-Roha. The drying was carried out in the tray dryer (Make M/s Aditi Association, India, Model: ATD-124) having capacity of 5kW. There were six numbers of trays in the dryer. The size of the tray was 81cm × 41cm × 3.4cm the *Moringa* pod pulp were dried in the thin layer in single layer. The mesh (square) size of tray was 2.52.5 mm. The extracted *moringa* pod pulp was uniformly spread on stainless steel trays in a thin layer to ensure uniform drying. The trays were placed in a tray dryer and dried at three different temperatures, viz., 40°C, 50°C and 60°C. The air velocity inside the dryer was 2-3 m/s. Drying was continued until constant weight was achieved, The weight loss with respect to the time was recorded from trays at different location in the tray dryer. The moisture content with respect to the time was calculated from drying data. The drying data include initial moisture content; weight loss, average moisture content with respect the time, drying rates, Moisture ratios, and final moisture content of *Moringa* pod pulp were also recorded. The drying time recorded at 40°C, 50°C and 60°C was 11hr 25min, 6hr 25min and 5hr hours respectively. After completion of drying, the samples were cooled to room temperature. The dried *moringa* pod pulp powder ground particles smaller than 425 μm, the dried pod powder was further ground in a home scale mixer grinder. The powdered samples were packed in airtight containers and stored at room temperature for further physicochemical analysis.

Procedure

***Moringa* Pod Pulp Powder**

Fresh *Moringa*

↓

Washing

↓

Cutting into 5 cm uniform pieces

↓

Blanching (60°C for 3 minutes)

↓

Peeling

↓

Pulp Separation

↓

Tray Drying (40°C / 50°C / 60°C)

↓

Powder Formation

↓

Storage

Fig. 1: Shows that flow chart for drying of *moringa* pod and its powder formation

1. Drying Characteristics

Moisture content (%db) versus time (min) and drying rate (g of water removed /100g of bone dry material/min) with respect to the moisture content was determined for tray drying of *moringa* pod pulp. Moisture ratio versus drying time(min) was also determined from the experimental data. The various mathematical models listed in table 1 were fitted to experimental data on moisture ratio versus drying time in min of *moringa* pod pulp dry with try drying. The moisture ratio determines the unaccomplished moisture change, defined as the ratio of free water still to be removed, at time (t) over the initial total free water (Henderson and Pabis, 1961).

2. Moisture ratio

The moisture ratio of *Moringa* pod pulp was calculated on dry basis using formula (Chakraverty, 2003).

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

Where,

MR = Moisture ratio; M = Moisture content at any time Ø,%(db); M_e = EMC, %(db); M_0 = Initial moisture content, %(db)

3. Drying Model

The drying rate of *moringa* pod pulp was calculated on dry basis using following formula (Chakraverty, 2003).

$$R = \frac{W_r}{T \times W_D} \times 100 \quad \ldots (3)$$

Where,

R = Drying rate (g/min); W = Amount of moisture removed(g); T = Time taken (min); W_D = Total bone dry weight of sample(g)

The root means square error was for the best fit of the model was determines for higher r_2 value and lower MSE;

$$\text{RMSE} = \left[\frac{1}{2}\sum_{i=1}^{n}\left(MR_{\exp} - MR_{pre}\right)^2\right]^{1/2} \quad \ldots (4)$$

Where,

MR_{exp} = experimental moisture ratio; MR_{pre} = predicted moisture; N and n are the numbers of observations and the number of constant respectively (Togrul and Pehlivan, 2004).

Table 1: Mathematical model tested with the moisture ratio of *Moringa* pod pulp

Sl. No.	Model	Equation	Reference
1	Newton	MR = exp(-kt)	Sargar and Swami, 2023
2	Page	MR=exp ($-kt^n$)	Nale and Swami, 2024
3	Henderson and Pabis	MR = aexp (-kt)	Sargar and Swami, 2024

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

4. 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 the lower the chi-square (χ^2) equation (5) and the lower value of RSME values, the better id goodness of fit (Santosh *et al.* 2024). According to (Wang *et al.* 2007 a). Reduced chi-square (χ^2) and root mean square error (RSME) can be calculated as follows;

$$\chi^2 = \frac{\sum_{i=1}^{N}\left(MR_{expi.i} - MR_{pre.i}\right)^2}{N-Z} \quad \ldots (5)$$

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 13.

5. Effective moisture diffusivity and activation Energy

The effective moisture diffusivity was calculated by using the simplified Fick's second law of diffusion model (Doymaz *et al.* 2004) as given in Eq (6);

$$\frac{\partial M}{\partial t} = D_{eff.\nabla^2}\ \mathrm{M} \quad \ldots(6)$$

Where,

M = moisture content (kg water/kg dry matter); t = is the time (s); D_{eff} = is 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).

$$\mathrm{MR} = \frac{8}{\pi^2}\sum_{i=1}^{n}\frac{1}{(2n-1)2}\exp\left(\frac{-(2n-2)^2\pi^2 D_{eff}t}{4H^2}\right) \quad \ldots(7)$$

Where,

H = is the half thickness of the slab m;

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

For long drying time Equation (7) can be simplified further (Lopez *et al.* 2000; Doymaz, 2004) as:

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

The diffusivity are typically determined by plotting the experimental drying data in the term of in (MR) vs drying time(t) in Equation (8), because the plot gives a straight line with the slope as follows:

$$\text{Slope} = \frac{\pi^2 D_{eff}}{4L^2} \quad \ldots (9)$$

Where,

L= half thickness (assumed for 2.5mm for slab)

6. Determination of effective Moisture Diffusivity and Activation Energy

The effective moisture diffusivity of the sample was estimated by using the simplifies mathematical Fick's second diffusion model. The activation energy of sample was obtained by plotting the natural logarithm of D_{eff} against the reciprocal temperature, then determine the slope of the straight line by using Eq (7) Lopez *et al.* (2000) and Simal *et al.* (1996) related temperature with Arrhenius expression as:

$$D_{eff} = D_0 \exp\left(\frac{-E_a}{R(T+273.15)}\right) \quad \ldots (10)$$

Where,

D_0 = is the pre-exponential factor of the Arrhenius equation, (m^2/s)

E_a = is the activation of energy

T = is the temperature of the air, (°C)

R = is the universal gas constant, (8.134J/mol. K),

Rearranging Equation (10) gives Equation (11):

$$D_{eff} = D_0 \exp\left(\frac{-E_a}{R(T+273.15)}\right) \quad \ldots (11)$$

Energy of activation can thus be calculated from equation (11), which gives a relationship between temperature and effective moisture diffusivity. The plot of versus 1/(T+273.5) gives a straight line (slop of $K_L = Ea/R$). Linear regression analyses were used to fit the equation to the experimental data to obtain the coefficient of determination (r^2).

Physiochemical analysis and functional Properties

1. Moisture Content

Moisture content was determined by as per the procedure of 2.4.1.

The following equation was used to determine the sample's moisture content;

$$\text{Moisture content (db) \%} = \frac{w1-w2}{w2} \times 100 \quad \ldots (12)$$

2. Ash Determination

The ash content of fresh materials and thermally processed at 40°C, 50°C and 60°C *Moringa oleifera* pods was determined as per the procedure developed by Akubugwo *et al.* (2007). About 3 g of fresh and thermally processed *moringa* pod paste was taken into a crucible and placed in a muffle furnace and heated at 550°C for 8 hours and the residue was determined. This procedure was repeated for four times and the average reading was reported.

$$\text{Ash (\%)} = \frac{Weight\ of\ crucible}{Weight\ of\ sample} \times 100 \quad \ldots (13)$$

3. Fat Determination

The fat determined by Ravichandran *et al.* (2010) the fat content of fresh and thermally-processed *moringa* pod powder at 40°C, 50°C and 60°C. The dry sample of *moringa* pod powder (5g) was weighted accurately into thimble and plugged with cotton the thimble was then placed in a soxhlet apparatus and extracted and extruded with anhydrous ether for 3 hrs. The ether was then evaporated and the flask with the residue dried in oven at 80°C to 100°C, cooled in a desiccators and weighed. The fat content was expressed as g/100g (AOAC, 1995). Each experiment was repeated four time to get the replication. The average reading of fat was reported.

$$\text{Crude fat content(g/100g)} = \frac{Weight\ of\ ether\ extract}{Weight\ of\ sample\ taken} \times 100 \quad \ldots (14)$$

4. Protein Determination

Protein content determined in the fresh and thermally processed *moringa* pod powder at 40°C, 50°C and 60°C by a micro-Kjeldal distillation method (AOAC 2000). The sample was digested by heating with concentrated sulphuric acid in the presence of digestion mixture, potassium sulphate and copper sulphate. 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 present nitrogen content of the sample was calculated by formula given below (15). The protein content was calculated by multiplying the amount of percent nitrogen with appropriate factor (6.25). Similar observations were taken four time for each treatment to get the replication.

$$\text{\%N} = 1.4 \times \frac{(mLHCL - mLblank) \times Conc.\ of\ HCL}{Weight\ of\ sample\ (g)} \quad \ldots (15)$$

$$\text{\%Protein} = \%\ N \times Factor\ (6.25) \quad \ldots (16)$$

5. Carbohydrate Content Determination

Carbohydrate content of *moringa* pod pulp powder thermally processed at 40°, 50° and 60° was determined by subtracting the total sum of protein, fiber, ash and fat from the total dry matter (AOAC, 2002). The carbohydrate was calculated by using following equation (17).

% carbohydrate = 100 – % protein + % fiber + % ash + % moisture content … (17)

6. Total Phenol Content

The phenolic content of fresh and thermally processed *moringa* pod pulp powder at 40°C, 50°C and 60°C was determined as per the procedure of Devanto *et al.* 2002. *Moringa* pod paste 0.1g mix with 80 % methanol centrifuge for 20 min. A few minutes later, 0.1ml of the extract was combined with 8.5 ml of distilled water and 0.5 ml of Folin- Ciocalteu, After adding 1 ml of a 35% sodium carbonate solution to the mixture, the absorbance at a wavelength of 765 nm was measured. Similar observations were repeated for four times and the average reading was reported.

7. Determination of Vitamin C Content

The method described by Ranganna *et al.* (1986) was used to determine the vitamin C concentration of fresh and thermally processed *moringa* pod pulp at 40°C, 50°C and 60°C. First, a conical flask was filled with 5 ml of normal ascorbic acid and 5 ml of metaphosphoric acid, for the purpose of titrating the sample, dye solution was placed in a burette. Through this technique, dye factor was produced. After that, a 5 g sample was titrated by adding 3% HPO_3. Similar procedure repeated four time and the was average value of Vitamin C was reported.

8. Determination of β-Carotene

The amount of β-Carotene of fresh and thermally processed *moringa* pod pulp at 40°C, 50°C and 60°C was determined by as per the procedure of Biswas *et al.* (2015). A test tube was filled with 1 g of sample and 5 g of cold acetone. After centrifuging the mixture, the supernatant was transferred to a different test tube, the absorbance at a wavelength 450 nm. The procedure was repeated four time and the average reading was reported.

9. Total Flavonoid Component

Total Flavonoid Component of fresh and thermally processed *moringa* pod pulp at 40°C, 50°C and 60°C was determined as per the procedure mentioned by Priecina *et al.* (2013) using a modified colorimetric test. The 0.25 ml of the extract and 0.75 ml of distilled water were combined in a test tube, and 5% of a 0.15 ml sodium nitrite ($NaNO_2$) solution was then added to the combination. Then, after waiting for five minutes, 0.3 ml of a 10% aluminium chloride ($AlCl_3$) solution and 1 ml of a 1 M sodium hydroxide solution were added. At 510 nm, the mixture's absorbance was determined using spectrophotometry (Shimadzu UV-1800, Tokyo, Japan). A calibration curve (Y = 0:0029x + 0:0169) for quercetin was established for the flavonoid contents, and the TFC was then expressed as quercetin equivalent (mg QE/100 g). The procedure was repeated for four times and average was reported.

10. Determination of DPPH Free Radical Scavenging Activity

DPPH free radical scavenging activity of fresh and thermally processed *moringa* pod pulp 40°C, 50°C and 60°C was determined as per the procedure Adiletta *et al.* (2016). The extract solution was initially made. Then, 2 ml of the extract sample was added to 2 ml of the DPPH (0.16 mM) methanol solution, which was then left in the dark. A solution without extract was used as a reagent blank, and the mixture's absorbance was calculated at 517 nm wavelength. The procedure was repeated four times and the average reading was reported.

DPPH radical scavenging activity = Abs control – Abs sample/ Abs control … (18)

RESULTS AND DISCUSSION

Convective hot air drying of *moringa* pod pulp

Fig. 2 shows the average Moisture content % (db) versus time (min) of *Moringa* pod pulp drying by convective hot air drying of different temperature 40°C, 50°C and 60°C. The average initial moisture content of 569.60 %(db) to 0.036 %(db) at 40°C; 613.72% (db) to 0.025 at 50°C; 749.67 % (db) at 60°C respectively. It took around 11 hr 25 min; 6 hr 25

min; and 5 hr time to dry the product at 40°C to 60°C respectively.

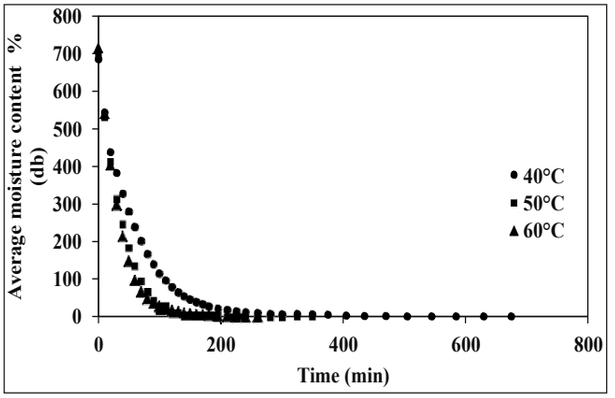

Fig. 2: Average moisture content (db) % with respect to time (min) for drying of moringa pod pulp at 40°C, 50°C and 60°C in convective hot air dryer

Fig. 3 shows variation in moisture ratio with respect to time in minute. During the drying experiment moisture ratio decreases from 1 to 2.70 × 10^{-5}, 1 to 2.28 × 10^{-5}, 1 to 1.11 × 10^{-5} at the drying temperature of 40°C, 50°C and 60°C respectively. The results obtained were in agreements with those reported by Santosh *et al.* 2024 for drying.

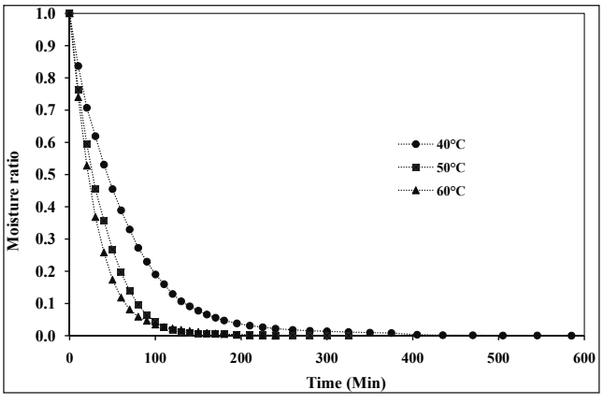

Fig. 3: Variation in moisture ratio with respect to time, (Min) for *moringa* pod pulp during convective hot air drying at different temperature

Fig. 4 shows the drying rate (g water removed /100g of bone dry material/min) with respect to moisture content %(db) of *moringa* pod pulp dried by convective hot air drying at 40°C, 50°C and 60°C. The initial drying rate of *moringa* pod pulp was 1.978 g of water removed /100 g of bone dry matter per minute and decrease up to 1.948 × 10^{-4} g of water removed / 100g of bone dry matter per minute at 40°C; 3.158 g /100 of bone dry matter per minute and decrease up to the 2.53 × 10^{-4} g of water removed /100 of bone dry matter per minute at 50°C; 3.676 g /100 of bone dry matter per minute at and decrease up to the 5.76 × 10^{-4} g of water removed /100 g of bone dry matter minute at 60°C. From Fig. 4. It is clear that drying took place in falling period. As the temperature of drying increase from 40°C to 60°C the drying also increase.

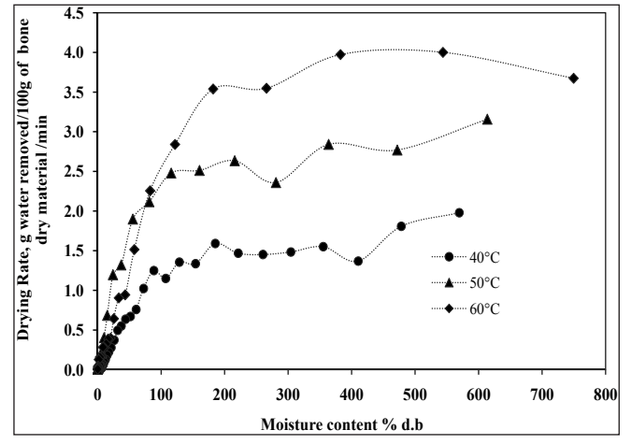

Fig. 4: Drying rate (g water removed /100g) of bone dry material / min) versus moisture content % (d.b) of *moringa* pod pulp dried by convective hot air drying of different drying temperature

Moisture removal inside the *moringa* pod pulp at 60°C was higher and faster than the other investigated temperature. Migration of surface moisture and evaporation rate from the surface to 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 increase drying rate (Santhosh *et al.* 2024) observed in beetroot slices. This increase in drying rate because of the increase heat transfer potential between the air and *moringa* pod pulp. Similar observation reported in Adekanye *et al.* 2023 observed in *moringa* leaves, Ferdusee *et al.* 2022 observed in fruits and vegetable, Zhu *et al.* 2014 observed in peach slices, Sargar and Swami, 2024

observed in Amaranthus leaves, Sargar and Swami, 2023 observed in spinach leaves.

Evaluation of thin layer drying model of *moringa* pod pulp

Table 2(a), 2(b), and 2(c) shows that the model parameter of various models fitted to the experimental data for Newton model, Hendeson, Page model. Among the model was 40°C, 50°C and 60°C respectively, the Page model was well fitted to the experimental data with $r^2 \geq 0.997$; $MSE \leq 0.003$ and chi square (x^2) ≥ 0.0009. Non-linear regression analysis was done according to three thin layer models for moisture ratio data. Table 2 shows the statistical regression result of the different models, including the drying model coefficient and comparison criteria used to evaluate goodness of the fit including the r^2, x^2 and *RSME* of *moringa* pod pulp at different temperature. In all cases r^2 values for the models were greater than 0.9691 indicating a good fit. The model parameter i.e. '*k*' was 0.015, 0.016 and 0.031 at 40°C, 50°C and 60°C respectively. The '*k*' value increase with increasing temperature from 40°C to 60°C. But it decreases at 60°C '*n*' value increase with the increase in the temperature. For all the temperature from 40°C to 60°C.

Table 2(a): Convective hot air drying at 40°C temperature

Sl. No.	Model name	Model parameter	R^2	MSE	χ^2
1	Newton	k = –0.016	0.998	0.006	0.00120
2	Henderson	$a = 1.022$ $k = 1.7 \times 10^{-2}$	0.998	0.005	0.0018
3	Page	$k = 0.015$ $n = 1.027$	0.998	0.005	0.009

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

Sl. No.	Model name	Model parameter	R^2	MSE	χ^2
1	Newton	$k = –028$	0.994	0.012	0.017
2	Henderson	$a = 1.105$ $k = 0.030$	0.994	0.008	0.001
3	Page	$k = 1.138$ $n = 1.027$	0.997	0.003	0.0001

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

Sl. No.	Model name	Model parameter	R^2	MSE	χ^2
1	Newton	$k = –0.034$	0.997	0.003	0.0001
2	Henderson	$a = 1.052$ $k = 0.035$	0.998	0.003	0.0016
3	Page	$k = 0.031$ $n = 1.025$	0.998	0.003	0.0007

Effective Moisture diffusivity of *moringa* pod pulp by convective hot air drying

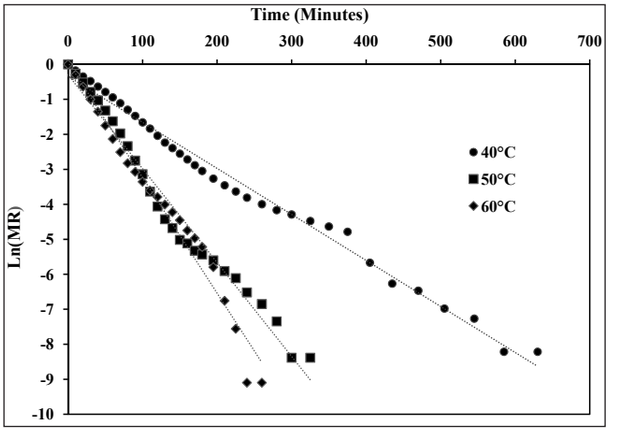

Fig. 5: *Ln* (*MR*) versus time, minute for effective diffusivity for convective hot air drying of *moringa* pod pulp

Fig. 5 shows Ln (MR) versus time (minute) for convective hot air drying of *moringa* pod pulp dried at 40°C, 50°C and 60°C respectively. The graph shows the straight line curve. The straight line equation $y = mx + c$ where the m is the slop of the line. Effective diffusivity (D_{eff}) at a time of *moringa* pod pulp was calculated by Eq (8). Table 3 shows the effective diffusivity of *moringa* pod pulp dried at 40°C, 50°C and 60°C. The effective diffusivity values were in the range of 3.34×10^{-8} to 8.36×10^{-8} for all the temperatures. As the temperature increases, the diffusivity value increases from 3.34×10^{-8}, 6.795×10^{-8} and 8.36×10^{-8} at 40°C, 50°C and 60°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; Falad and Solademi, 2010). Generally,

effective moisture diffusivity increase with increase air temperature Falad and Solademi, 2010).

It was observed that (D_{eff}) values increase greatly with increasing drying temperature and thickness. When sample 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).

Table 3: Effective diffusivity and activation energy of *moringa* pod pulp at different temperature

Temperature	D_{eff} ($m^2.s^{-1}$)	E_a (kJ/mole)
40°C	3.34699×10^{-8}	
50°C	6.79541×10^{-8}	32.927
60°C	8.36748×10^{-8}	

The values obtained for effective diffusivity from this study was 3.34699×10^{-8}, 6.79541×10^{-8} and 8.36748×10^{-8} during the temperature of 40°C, 50°C and 60°C respectively. Similar results have been observed for beetroot slices ranges from 2.10962×10^{-9}, 5.03063×10^{-9}, 1.03858×10^{-8} and 1.34691×10^{-8} (Nale and Swami, 2024). The similar results also observed in Amaranthus leaves 3.114×10^{-10}, 5.735×10^{-10}, and 7.729×10^{-10} for temperature 45°C, 55°C and 65°C (Sargar and Swami, 2024).

Activation energy of *moringa* pod pulp

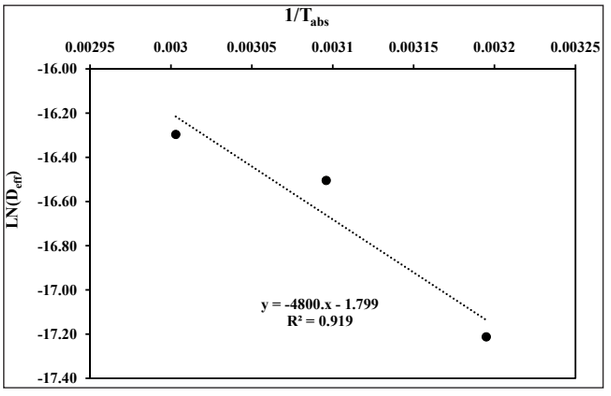

Fig. 6: *Ln* (D_{eff}) vs / T_{abs} for dried *moringa* pod pulp

Fig. 6 shows that *Ln* (D_{eff}) vs 1/ T_{abs} for dried *moringa* pod pulp at 40°C, 50°C and 60°C the activation energy was calculated by plotting the natural logarithm of D_{eff} vs reciprocal of absolute temperature studied. The activation energy for moisture diffusion calculated from the slop of straight lines graphs are given in Table (3). The activation energy (E_a) for moisture diffusion was found to be 32.927 kJ/mole. The energy activation (E_a) are reported in the literature, for convective hot air drying of yam was 8.831 (Sobukola *et al.* 2008), in beetroot slices reported 0.8160 (Nale and Swami, 2024) for sweet potato slices 22.7-23.2kJ/mole (Doyomaz *et al.* 2011) for apple slices 19.96-22.62 kJ/mole. *Moringa* pod have the lower activation energy than the leaves because due to the higher moisture diffusivity as discussed above. So *moringa* pod pulp require the moderate activation energy for the mass of diffusion during hot air drying.

The result indicated a linear relationship between (*Ln* D_{eff}) and ($1/T_{abs}$) as plotted in Fig. 6 for Moring pod pulp dried by convective drying at 40°C, 50°C and 60°C. The diffusivity constant or pre exponential factor of Arrhenius equation (D_{eff}) and activation of energy (E_a) calculated from the linear regression are 1.60×10^{-2} m/s² and 32.927 kJ/mol for *moringa* pod pulp Eq (10) shows the effect of temp on effective diffusivity of *moringa* pod pulp.

$$\left(D_{eff}\right) = 1.60 \times 10^{-2} \exp\left(-\frac{32.927}{R\left(T + 273.15\right)}\right) \quad \ldots (18)$$

Evaluation of quality parameter for dried for *moringa* pod pulp

1. Moisture

Table 4(a) shows the moisture content of fresh *moringa* pod pulp and convective hot air dried at 40°C, 50°C, and 60°C *moringa* pod pulp. The moisture content of fresh *moringa* pod pulp's was 88.89±2.585, moisture content of *moringa* pulp pod were 5.14±0.893, 4.65±0.629, and 3.520±0.709 at 40°C, 50°C, and 60°C, respectively. The decrease in *Moringa* pod pulp moisture content with respect to increase in temperature is significant at P≤0.01. This unevenly demonstrates how increasing the drying temperature improves the product's shelf durability by lowering the moisture content.

Table 4: Physiochemical chemical properties of *moringa* pod pulp before and after drying

Sl. No.	Chemical constituent	Fresh Sample	40°C	50°C	60°C	SE(m)	CD
1	(a) Moisture	88.89±2.585	5.145±0.893	4.653±0.629	3.520±0.709	0.262	0.924
2	(b) Ash	0.585±0.005	6.500±0.016	5.725±0.028	4.420±0.024	0.012	0.042
3	(c) Fat	0.425±0.095	3.363±0.505	4.103±0.150	4.420±0.024	0.210	0.740
4	(d) Protein	14.33±0.33	9.490±0.531	6.130±0.480	5.798±0.267	0.182	0.643
5	(e) Carbohydrate	4.44±02.995	75.453±0.553	79.390±0.676	81.350±0.840	0.466	1.663
6	(f) Vit 'c'	226.21±9.464	187.5±6.454	164.5±16.360	116.2±11.086	6.784	23.932
7	(g) β Carotene	18.93±1.081	16.185±0.952	5.593±0.436	2.118±0.124	0.346	1.220
8	(h) Phenol	1127±50.3	2888±169	2256±340	2114±317	517.369	N/A
9	(i) Flavanoid	134.49±134.29	518.0±1.73	449.6±55.286	475.1±24.537	13.267	46.801
10	(j) DPPH	38.42±0.086	82.743±0.009	68.403±0.005	61.208±0.009	0.28	0.099

Studies on fresh vegetables, which typically have a moisture percentage of 80–95%, are consistent with the high initial moisture level (≈89%) (Ranganna, 2010). It has been demonstrated that fresh drumstick (*moringa*) pods and other vegetables, such as carrot and pumpkin, have similar values (Sagar and Kumar 2010). After drying, the moisture content dropped to less than 6%, which is within the permitted storage limit for dried food powders (below 8–10%), in order to stop microbial growth and deterioration (Fellows, 2009). The lowest moisture content (3.52%) at 60°C demonstrates more efficient moisture removal due to greater heat transmission and vapor pressure gradient.

2. Ash Content

Table 4(b) shows the ash content of fresh *moringa* pod pulp and convective hot air dried at 40°C, 50°C, and 60°C *moringa* pod pulp. The ash content for fresh *moringa* pod pulp was 0.585±0.005. The ash content decreases from 6.500±0.016, to 5.725±0.028 and 4.420±0.024 w.r.t. temperature increases 40°C, 50°C, and 60°C respectively. The drying process significantly decrease at P≤0.01 the ash content in *moringa* pod pulp. This rise in ash content during drying is attributed to the concentration of mineral elements following moisture removal. Nevertheless, a pattern indicating a reduction in ash content with higher drying temperature was observed it may be due to mineral leaching and thermal degradation caused by the blanching pretreatment. These findings are similar to these were reported by (Doymaz *et al.* 2007) and (Sengev *et al.* 2013), who noted that while drying raised ash content, pretreatment method like blanching led to some mineral loss. The measure value align with the typical range (3-12 %) documented for dried vegetables.

3. Fat Content

Table 4(c) shows the Fat content of fresh *moringa* pod pulp and convective hot air dried at 40°C, 50°C, and 60°C *moringa* pod pulp. The Fat content of fresh *moringa* pod pulp's was 0.425±0.095, Fat content of *moringa* pulp pod were 3.363±0.505, 4.103±0.150 and 4.420±0.024 at 40°C, 50°C, and 60°C respectively. The increase in fat content with increase in temperature is significantly difference at P≤0.01. The concentration effect brought on by moisture removal is responsible for the rise in fat content with drying temperature. The relative percentage of fat rises as the water content falls. Higher drying temperatures may also cause cell structure to break down, which would improve the release and extractability of bound lipids. The results of Anwar *et al.* (2007) and Gopalakrishnan *et al.* (2016), who found low fat content in fresh *moringa* pods and elevated values after drying due to concentration effects, are consistent with the obtained values.

4. Protein Content

Table 4(d) shows the Protein content of fresh *moringa*

pod pulp and convective hot air dried at 40°C, 50°C, and 60°C. Protein content of fresh *moringa* pod samples were 14.33±0.33. The protein content of *moringa* pod pulp dried at temperature from 40°C, 50°C, and 60°C were 9.490±0.531, 6.130±0.480, and 5.798±0.267 respectively. The decrease in protein content with increase in temperature is significantly difference at P≤0.01. The reduction in protein content may be attributed to thermal denaturation, Maillard reactions, and leaching losses during blanching pretreatment. Similar decreasing trends were reported by Doymaz *et al.* (2007) and Adepoju *et al.* (2012). However, the protein content observed in raw samples was higher than commonly reported values (2–5%), indicating possible differences in calculation basis or experimental error Razzak *et al.* (2022). The protein values of dried samples were within the acceptable range reported for vegetable powders.

5. Carbohydrate

Table 4(e) shows the carbohydrate content of fresh *moringa* pod pulp and convective hot air dried at 40°C, 50°C, and 60°C *moringa* pod pulp. Fresh *moringa* pod pulp's carbohydrate content was 4.44±02.995 to it was increased to 75.453±0.553 at 40°C, 79.390±0.676 at 50°C, and 81.350±0.840 at 60°C drying air temperature. Increase in carbohydrate content with respect to increase in drying air temperature from 40°C to 60 °C was significant at P≤0.01. The primary cause of this rise is the elimination of moisture during the drying process, which leads to a concentration of nutrients based on dry weight (Wang *et al.* 2007; Doymaz, 2005). Thermal degradation and Maillard reactions may cause slight alterations at higher temperatures (Fellows, 2009). Variations in protein, fat, and ash levels also affect the final numbers because carbohydrates are calculated by difference. Overall, the findings show that, within the examined temperature range, moisture loss has a bigger impact than thermal depreciation. Dried plant materials have shown similar patterns for amaranthus (Rajput *et al.* 2020; Akubugwo *et al.* 2007).

6. Vitamin 'C'

Table 4(f) shows the Vitamin 'c' content of fresh *moringa* pod pulp and convective hot air dried at 40°C, 50°C, and 60°C *moringa* pod pulp. The fresh sample of *moringa* pod pulp had the highest vitamin C content 226.21±9.464. Dried samples had 187.5±6.454 of vitamin C at 40°C, 164.5±16.360 at 50°C, and 116.2±11.086 at 60°C. The Vitamin 'c' content of *moringa* pod samples dried at temperature 40°C to 60 °C decreased as the temperature of drying increases significantly at P≥0.01 as the drying temperature increase. The significant decrease in vitamin C is explained by oxidative degradation during drying and its heat sensitivity. The findings are consistent with Sengev *et al.* (2013), who found that fresh *moringa* products have vitamin C contents between 120 and 220 mg/100 g, with significant processing losses. Madhlopa *et al.* (2007) found that drying vegetables reduced their vitamin C content by 30–80%. According to Goyal *et al.* (2007) for leafy vegetables and Sultana *et al.* (2012) for fruits and vegetables, vitamin C degrades more at higher drying temperatures.

7. Beta Carotene

Table 4(g) shows the β-carotene content of fresh *moringa* pod pulp and convective hot air dried at 40°C, 50°C, and 60°C *moringa* pod pulp. *Moringa* pod pulp carotene level was determined to be 18.93±1.081 in the fresh sample. As the *moringa* pod pulp dried at 40°C, 50°C, and 60°C, the Beta Carotene decreased from 16.185±0.952, 5.593±0.436, and 2.118±0.124 respectively. The decrease Beta Carotene with respect to increase in temperature in significant at P≥0.01, respectively. Its sensitivity to heat, light, and oxygen causes oxidative destruction during drying, which is the reason for the decrease in β-carotene. The findings are consistent with those of Saini *et al.* (2014), who found that thermal processing of *Moringa oleifera* leaves degraded carotenoids by 20–90%. Goyal *et al.* (2007) reported for leafy vegetables and Sultana *et al.* (2012) for fruits and vegetables reported similar results, showing notable β-carotene

losses at higher drying temperatures. However, varietal variations, maturation stage, and analytical techniques could be the cause of the comparatively higher initial β-carotene level found in this study.

8. Phenolic Content

Table 4(h) shows the phenolic content of fresh *moringa* pod pulp and convective hot air dried *moringa* pod pulp at 40°C, 50°C, and 60°C. The fresh *moringa* pod pulp had 1127±50.3 phenolic content. After blanching and drying, the total phenolic content of *moringa* pod pulp was 2888±169 at 40°C; 2256±3402 at 50°C and 2114±317 at 60°C, a decrease in phenolic content was noted at higher drying temperatures this decrease in phenolic content is non significantly P≤0.01.

Blanching at 60°C for three minutes inactivated polyphenol oxidase enzymes and stopped oxidative destruction, which may be the reason for the rise in phenolic content following processing. Drying also made it easier for plant cell walls to break down, which improved the release and extractability of bound phenolic chemicals. Dewanto *et al.* (2002) and Sultana *et al.* (2012) reported similar results for tomato and fruits and vegetables. According to Turkmen *et al.* (2005) and Kamiloglu *et al.* (2015), heat degradation and oxidation of phenolic compounds may be the cause of the decrease in phenolic content at higher temperatures in pepper, squash, green beans, peas, leek, broccoli and spinach and for fruits and vegetables. By stopping enzymatic losses, blanching has also been demonstrated to enhance the retention of phenolic chemicals (Negi & Roy, 2000). Overall, it was discovered that the best drying temperature for maintaining phenolic content was 40°C.

9. Flavonoid Content

Table 4(i) shows the flavonoid content of fresh *moringa* pod pulp and convective hot air dried at 40°C, 50°C, and 60°C *moringa* pod pulp. The fresh *moringa* pod pulp had 134.49±134.29 in flavonoid content. After blanching and drying, the flavonoid concentration of *moringa* pod pulp increased up to 518.0±1.73 at 40°C, At 50°C, there was a tiny drop 449.6±55.286, while at 60°C, there was a slight increase 475.1±24.537. The decrease in flavonoid content significant at P 0.01 at. Blanching at 60°C for three minutes, which inactivated oxidative enzymes and improved the stability of flavonoid molecules, may have contributed to the rise in flavonoid concentration following processing. Drying also made it easier for cell walls to break down, which improved the release and extractability of bound flavonoids. Sultana *et al.* (2012) and Dewanto *et al.* (2002) obtained similar results for tomato and fruits and vegetables. According to Kamiloglu *et al.* (2015) and Turkmen *et al.* (2005), thermal degradation and oxidation of heat-sensitive chemicals may be the cause of the decrease in flavonoid concentration at 50°C reported in pepper, squash, green beans, peas, leek, broccoli and spinach and for fruits and vegetables. Improved extraction efficiency and potential intermediate compound synthesis during heat processing could be the cause of the modest increase seen at 60°C. By rendering degradative enzymes inactive, blanching has also been shown to enhance the preservation of antioxidant substances (Negi & Roy, 2000).

10. DPPH Content

Table 4(j) shows the phenolic content of fresh *moringa* pod pulp and convective hot air dried at 40°C, 50°C, and 60°C *moringa* pod pulp. DPPH radicals scavenging activity was 38.42±0.086 in the fresh sample. As the temperature of drying increases from 40°C to 60 °C the radical scavenging activity (DPPH Content) of decreases to 82.743±0.009 at 40°C, 68.403±0.005 at 50°C and 61.208±0.009 at 60°C, this decrease in DPPH Content with respect to Temperature is significant at P≤0.01. The combined effects of blanching and drying are responsible for the post-processing rise in DPPH activity. By inactivating oxidative enzymes like peroxidase and polyphenol oxidase, blanching at 60°C for three minutes helps stop the breakdown of antioxidant molecules. Additionally, it increases cell wall permeability, which makes it easier for bound phenolic and flavonoid chemicals to be released. These compounds play a major role in antioxidant action. Negi and Roy (2000) reported similar results, noting enhanced antioxidant component

retention in blanched veggies. Additionally, drying at a moderate temperature (40°C) increases the concentration of bioactive chemicals by removing moisture and improving their extractability, which raises the activity of DPPH radical scavenging. This is consistent with the findings of Dewanto *et al.* (2002) and Sultana *et al.* (2012), who found that thermal processing increased antioxidant activity because phenolic chemicals were more readily available in tomato and fruits and vegetables. The partial oxidation of phenolic compounds and the thermal degradation of heat-sensitive antioxidants like vitamin C and β-carotene may be responsible for the decrease in DPPH activity at higher temperatures (50°C and 60°C). These findings are in line with those of Turkmen *et al.* (2005) and Kamiloglu *et al.* (2015), who found that severe heat treatment lowers antioxidant activity in pepper, squash, green beans, peas, leek, broccoli and spinach and for fruits and vegetables.

CONCLUSION

The comprehensive study highlights the significant influence of drying method on composition and bioactive properties of *Moringa* pod pulp. The drying of *Moringa* pod pulp occurred in the falling rate period. The *Moringa* pod pulp were average initial moisture content of 569.60 %(db) to 0.036 %(db) at 40°C; 613.72% (db) to0.025 at 50°C;749.67 % (db) at 60°C respectively. It took around 11 hr 25 min ;6 hr 25 min; and 5 hr time to dry the product at 40°C to 60°C respectively. Experimental data of moisture ratio with respect to time of *Moringa* pod pulp drying were fitted to the page model which better describes than other models i.e., Henderson and Newton model. The effective diffusivity values were in the range of 3.34×10^{-8} to 8.36×10^{-8} for all the temperatures. As the temperature increases the diffusivity value increase from 3.34×10^{-8}, 6.795×10^{-8} and 8.36×10^{-8} m^2/s at 40°C, 50°C and 60°C respectively. The activation energy (E_A) for moisture diffusion was found 32.927 kJ/mole. Effect of quality parameter i.e. moisture, ash, fat, protein, carbohydrate, vit 'c', phenolic content, flavonoid, DPPH, beta carotene on fresh MPP and dried MPP at 40°C, 50°C and 60°C respectively. The nutrient content of the, *Moringa* pod pulp decrease with increasing temperature, the drying temperature affects the nutritional quality of the *moringa* pod pulp powder. Better retention observed at 40°C Moisture 4.145, Ash 6.500, Fat 3.363, Protein 9.490, Carbohydrate 75.453, vit 'C' 187.5, beta carotene 16.185, Phenol 2888, Flavonoid 518.0, DPPH 82.743 respectively.

GENERATIVE AI DECLARATION

The author(s) confirm that there was no use of artificial intelligence (AI)-assisted technology for assisting in the writing or editing of the manuscript, and no images were manipulated using AI. The authors developed and verified all scientific content, data analysis, interpretation of results, and conclusions. The authors take full responsibility for the accuracy, integrity, and originality of the work presented, and no AI tool was listed as an author.

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