Thin Layer Drying Characteristics of Basil (*Ocimum Gratissimum* L.) Leaves

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Abstract—*Fresh basil leaves were manual nibbing leaves from stem and root, washed, cleaned and 45cm×30cm stainless steel perforated trays size. In this technique, samples were subjected to tray drying at different temperature ranges (45, 50 & 55°C) with different loading density (2.5, 3.0 & 3.5 kg/m^2). Based on the result observed, it can be concluded that, increased in temperature and decreased loading density, which increased drying rate and decreased the drying time. The whole drying took place in falling rate period only, due to uniform moisture diffusion from the basil leaves as where dried with temperature of 50°C for 2.5 kg/m^2 loading density as a best treatment combination to produce best quality dehydrated basil leaves. In which the average initial moisture content was found 461.80 (%db) and average final moisture content found 3.88 (%db). Midilli model was found to describe the drying behaviour of basil leaves most precisely (highest R^2 = 0.9993; least RMSE = 0.0125). The effective moisture diffusivity values ranges from 5.0×10^{-9} m^2/s to 3.64×10^{-7} m^2/s and activation energy values ranges from 44.98 kJ/mol to 42.63 kJ/mol. The nutritional analysis of the fresh basil leaves in terms of moisture content, protein content, ash content, carbohydrate content and coliform count was found 82.26%, 6.93%, 2.78%, 6.83%, nil (CFU/g) with respectively. The nutritional analysis of the dried basil leaves in terms of protein content, ash content, carbohydrate content, coliform count and rehydration ratio was found 6.73%, 13.20 %, 7.27 %, nil (CFU/g) and 5.89 with respectively. During storage study the sensory evaluation was done in 3 months, the highest overall acceptability was founds to be 7.9. The basil leaves dried with temperature of 50°C for 2.5 kg/m^2 loading density produce best quality dehydrated basil leaves.*

(Key words: Drying kinetics, activation energy, effective moisture diffusivity, drying, moisture ratio, drying time, rehydration ratio, protein content, carbohydrate content, ash content, coliform count, models, basil leaves, tray dryer,

1. INTRODUCTION

Ocimum gratissimum is a small erect plumb plant with many branches usually not more than 1 m to 2 m high with a taproot and many adventitious side rootlets. The leaves are 6.3 cm to 12.5 cm long, elliptic - lanceolate, acute, coarse lycrenateser - rate, pubescent on sides, gland dotted, base cuneate petioles are 2.5 cm to 6.3 cm long, slender, more or less pubescent [1].

Drying is one of the oldest methods for agricultural food preservation and it represents a very important aspect in agricultural food processing. The main aim of drying products is to allow longer periods of storage, minimize packaging requirements and reduce shipping weights [2].

Thin layer equations describe the drying phenomena in a united way, regardless of the controlling mechanism. They have been used to estimate drying time of several products and to generalize drying curves. In the development of thin layer drying models for agricultural products, generally the moisture content of the material at any time after it has been subjected to a constant relative humidity and temperature conditions is measured and correlated to the drying parameters [3-4].

Although scented leaves are drought tolerance, it is not available in every community and scare, mostly in the dry season [5]. These can deteriorate very easily therefore drying becomes an option for both storage and transportation. Many drying studies have been done in *Ocimum sanctum* but few drying studies are conducted on *Ocimum gratissimum.* Therefore, the present study is taken up to obtain the effect of drying temperature on drying characteristics and kinetics of basil leaves of *Ocimum gratissimum* for value addition with the following objectives.

1. To investigate the influence of different drying air temperature and tray load on drying kinetics of basil leaves.
2. To evaluate a suitable thin layer drying model to describe the drying behavior of basil leaves.
3. To evaluate the quality characteristics of dehydrated basil leaves during storage.

2. MATERIALS AND METHODS

2.1 Sample Preparation

Washed basil leaves were weighed in digital weighing balance (Denver, Capacity: 610 g, least count: 0.01 g) according to the loadaing density of 2.5, 3.0, 3.5 Kg/m^2 and placed in a perforated stainless steel trays of 0.135 m^2 area giving a sample size of 500 g each treatment by using another trays of same area.

2.2 Washing

The fresh basil leaves was procured from kitchen garden in Dediapada and thoroughly cleaned before manual nibbing. The roots and stem were removed and basil leaves were separated and cleaned in cold water to remove soil and dust particles if any attached to it.

2.3 Drying in tray dryer

To determine the drying kinetics, basil leaves were dried on perforated trays in tray dryer (cabinet type, Aksher Electronics, India) at 45ºC, 50ºC and 55 ± 1ºC. Basil leaves were spread uniformly in 45 cm × 30cm stainless steel perforated trays which were placed inside the dryer with three replication. The drying temperature ranged from 45 - 55ºC with an increment of 5 ºC. Weight of samples was recorded with an interval of 5 min for first 30 min of observation and interval increased to 15 min and 30 min in later stages of drying to determine the moisture content at different drying times. The drying was carried up to a safe moisture level of 4-6%.

2.4 Moisture content

Moisture content of fresh basil leaves was determined using method as described in [6].

2.5 Drying rate

The drying rate during the experiments was calculated using the following formula

$$\text{Rate of drying} = \frac{dM}{dt} = \frac{M_{t+dt} - M_t}{dt} \quad (1)$$

Where,
M_t = Moisture content at instant of time, t.
M_{t+dt}= Moisture content at time after a successive interval of,dt.
The overall drying rate was calculated as the ratio of difference of initial and final moisture content ($M_0 - M_f$) and total drying time (t_T). The overall drying rate was calculated as follows.

$$\text{Overall drying rate} = \left(\frac{dM}{dt}\right) = \frac{M_0 - M_f}{t_T} \quad (2)$$

2.6 Mathematical modeling of drying kinetics

Experimental moisture content data of basil leaves during tray drying were converted to moisture ration using eq (3):

$$MR = \frac{M_t - M_e}{M_0 - M_e} \quad (3)$$

Where,

MR = the moisture ratio (dimensionless)

M_0 =the initial moisture content

M_t = the moisture content at time t

M_e = the equilibrium moisture content

The eq. (3) can further simplified to $MR = \frac{M_t}{M_0}$ as the values of M_e is relatively small compared to M_0 and M_t for long drying time, hence the error involved in the simplification by assuming that M_e is equal to zero is negligible. All moisture contents are denoted in dry basis (kg water/ kg dry matter).

The moisture ratio curve can better explain the drying behavior than that of the moisture content curve, as the initial was one in each experimental data irrespective of the initial moisture content if varies. The experimental data of these moisture ratios versus drying time were fitted to drying models to describe the drying behavior of basil leaves. The following semi-empirical models were tested to describe the drying behavior of basil leaves.

1). Henderson and Pabis model ;

$$MR = \frac{M - M_e}{M_0 - M_e} = ae^{-(kt)} \quad (4)$$

2). Logarithmic model ;

$$MR = \frac{M - M_e}{M_0 - M_e} = ae^{-(kt)} + c \quad (5)$$

3). Page model ; (6)

$$MR = \frac{M - M_e}{M_0 - M_e} = e^{-(kt^n)}$$

4). Midilli model ;

$$MR = \frac{M - M_e}{M_0 - M_e} = ae^{-(kt^n)} + bt \quad (7)$$

Where k and b are the drying constant (1/min); and a and n are dimensionless model parameters.

2.7 Effective moisture diffusivity

Fick's second law of diffusion equation, symbolized as a mass-diffusion equation for drying of agricultural products in a falling rate period, is shown in the following equ.

$$\frac{\partial M}{\partial t} = D_{eff} \cdot \frac{\partial^2 M}{\partial x^2} \quad (8)$$

By using appropriate initial and boundary conditions, Crank (1975) gave the analytical solutions for various geometries and the solution for slab object with constant diffusivity is given as:

$$MR = \frac{8}{\pi^2} \sum_{n=0}^{\infty} \frac{1}{(2n+1)^2} \exp\left(-(2n+1)^2 \pi^2 \frac{D_{eff}\, t}{L^2}\right) \quad (9)$$

Where, D_{eff} is the effective diffusivity (m^2/s); L is the thickness of samples (m); t is the drying time (s) and n is a positive integer, the Eq. (9) can be simplified by taking the first term of Eq. (9):

$$MR = \frac{8}{\pi^2} \exp\left(-\frac{\pi^2 D_{eff} t}{L^2}\right) \quad (10)$$

Eq. (6) is evaluated numerically for Fourier number,

$F_0 = D_{eff} \times t/L^2$, for diffusion and can be rewritten as:

$$MR = \frac{8}{\pi^2} \exp(-\pi^2 F_0) \quad (11)$$

$$\ln(MR) = \ln\left(\frac{8}{\pi^2}\right) + (-\pi^2 F_0) \quad (12)$$

Thus: $$F_0 = -0.101 \ln(MR) - 0.0213 \quad (13)$$

The effective moisture diffusivity was calculated using Eq. (15) as:

$$D_{eff} = \frac{F_0}{\left(-\frac{t}{L^2}\right)} \quad (14)$$

The effective moisture diffusivity (D_{eff}) was estimated by substituting the positive values of $(F_0)_{th}$ and the drying time along with the thickness of sample (L) for each corresponding moisture contents under different drying conditions. The average moisture diffusion coefficients were typically determined by plotting experimental drying data in terms of ln(MR) versus drying time (t), because the plot gives a straight line with a slope as $\frac{\pi^2 D_{eff}}{L^2}$.

2.8 Activation energy

Simal *et al.*, (1996) reported the effective diffusivity can be related with temperature by Arrhenius equation:

$$D_{eff} = D_0 \exp\left(-\frac{E_a}{R(T+273.15)}\right) \quad (15)$$

Where, D_0 = the constant in Arrhenius equation in (m^2/s); E_a = activation energy (kJ/mol); R = universal gas constant (8.314 J/mol.K); and T is the temperature in ºC. Equation (15) can be rearranged in the form of:

$$\ln(D_{eff}) = \ln(D_0)\exp\left(-\frac{E_a}{R(T+273.15)}\right) \quad (16)$$

The activation energy can be calculated by plotting a curve between $\ln(D_{eff})$ versus 1/(T+273.15).

2.9 Rehydration ratio

Dried basil leaves were rehydrated by immersing in warm water (about 60ºC) and cooled down up to room temperature. About 5g of dried basil leaves samples were observed that samples take almost equal time (720 min at 2.5 kg/m², 780 min at 3.0 kg/m² and 840 min at 3.5 kg/m² (100 ml) dipped in water for 20 min. and then it was filtered through filter paper. The rehydrated basil leaves samples were then weighed. The rehydration ratio was calculated as follows. [6].

$$\text{Rehydration ratio} = \frac{W_r}{W_d} \quad (17)$$

Where,

W_r = the rehydrated weight, g

W_d = the dehydrated weight, g

2.10 Statistical analysis of drying kinetics

Curve expert (Trial version 1.4) software (Microsoft Corporation, Mississippi, USA) was used to fit the mathematical models to experimental data. Two comparative indices were used as goodness and to select the best model such as: (1) Coefficient of Determination (R^2) and (2) the Root Mean Square Error (RMSE).

These indices are as follows:

$$R^2 = 1 - \frac{\sum_{i=1}^{N}[MR_{exp,i} - MR_{pre,i}]}{\sum_{k=1}^{N}\left[MR_{pre,i} - \frac{\sum_{k=1}^{N} MR_{pre,i}}{N}\right]} \quad (18)$$

and

$$RSME = \left[\frac{\sum_{i=1}^{n}[MR_{exp,i} - MR_{pre,i}]^2}{N}\right]^{\frac{1}{2}} \quad (19)$$

Where,

$MR_{exp,i}$ = experimental moisture ratio of i^{th} data

$MR_{pre,i}$ = predicted moisture ratio of i^{th} data

N = number of observations

The model is said to be good if R^2 value is high and RMSE value is low.

2.11Quality Analysis

For quality analysis after drying and storage studies following methods were adopted. Protein content by Lowry's method (1951); Total Ash Content, Total Carbohydrate Content, Microbiological parameter – Coliform count (CFU/g) and Sensory evaluation by [6].

3. RESULTS AND DISCUSSION

3.1 Effect on moisture content

The drying time ranged from 540 min, (2.5 kg/m^2 and at temperature of 55 °C) to 1080 min, (3.5 kg/m^2 and at temperature of 45 °C), being generally lower at higher drying temperatures. It was observed that drying time increases with loading density at a particular temperature (960 min at 2.5 kg/m^2, 1020 min at 3.0 kg/m^2 and 1080 min at 3.5 kg/m^2 for 45 °C in samples). Again, it was for 50°C in samples). The final moisture content varied from 4 to 6 (% db).

3.2 Effect on drying time

From the Fig. 1 it can be seen that the minimum value for drying time was noted to be 540 minutes for the treatment T_3. The maximum value of drying time was noted to be 1080 minutes for the treatment T_7. This result indicated that the decrease in drying rate with drying time was remarkable during the period of tray drying and then slowly decreased with time. Effectively the drying rate of basil leaves decreased considerably by tray drying during first five minutes.

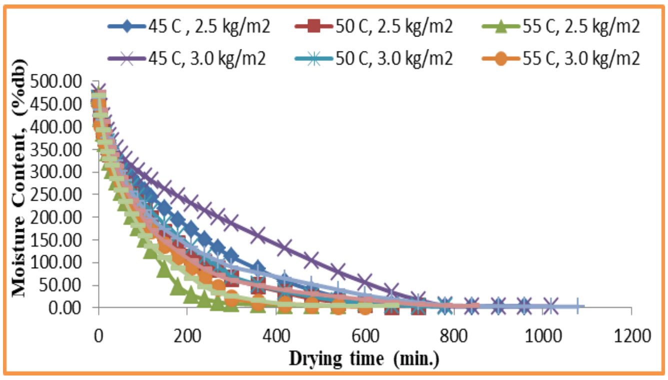

Chart. 1. Variation of moisture content with drying time at different temperature levels

3.3 Effect on drying rate

The relationships between drying rate and moisture content (% db) with the respective drying temperatures and loading densities are shown in chart 2 to 4. From the process took longer time as compare to other drying temperature. At temperature (45ºC) increased and loading density (2.5, 3.0 and 3.5 kg/m^2) resulted in decreased drying rates 0.470 (% db/min.), 0.461 (% db/min.) and 0.424 (% db/min.), respectively. At temperature (50ºC) increased and loading density (2.5, 3.0 and 3.5 kg/m^2) resulted in decreased drying rate of 0.636 (% db/min.), 0.589 (% db/min.) and 0.559 (% db/min.), respectively. At temperature (55ºC) and loading density (2.5, 3.0 and 3.5 kg/m^2) the drying rate was decreased 0.858 (% db/min.), 0.744 (% db/min.) and 0.702 (% db/min.), respectively.

3.4 Validation of semi-empirical mathematical models for drying kinetics.

Drying curves of moisture ratio vs. drying time reflecting different temperature levels for 2.5 kg/m^2 loading density
the effect of temperature and sample thickness are shown in Fig.5. From the figures it can be seen that drying time was inversely proportional to temperature and loading density.

The moisture ratio vs. drying time curve can better explain a drying behaviour than moisture content vs. drying

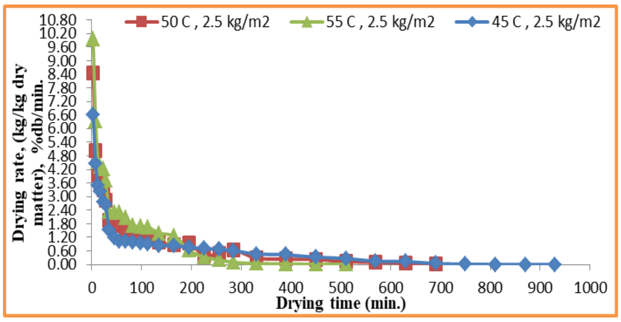

Chart. 2 Variation of drying rate with drying time at different temperature levels for 2.5 kg/m^2 loading density

Variation of drying rate with drying time at time curve as the initial value was one in each experimental data irrespective of the initial moisture content. To describe the effect of temperature and loading density on drying kinetics of basil leaves, four semi-empirical thin layer drying models such as Henderson and Pabis model, Logarithmic model, Page's model and Midilli model were used. The moisture ratio and drying time data were fitted to this four drying models.

All four models were adequate to describe the thin layer drying characteristics of basil leaves since that the highest value of R^2 and the lowest value of RMSE were obtained with Midilli model for all the treatments of drying treatments of drying experiment. All four models were adequate to describe the tray drying characteristics of basil leaves since lowest R^2 value and highest RMSE were found to be 0.9993 and 0.0125 respectively, (treatment T_2, midilli model) that is adequacy of $R^2 > 90$ % is fulfilled by all models.

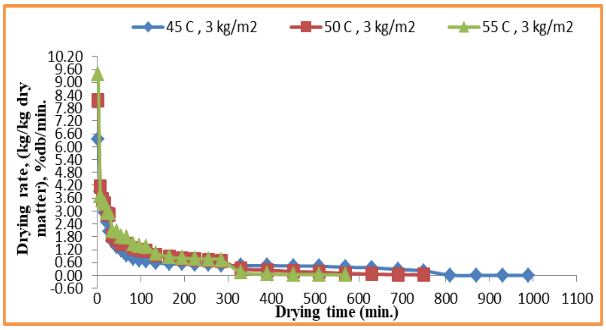

Chart. 3 Variation of drying rate with drying time at different temperature levels for 3.0 kg/m^2 loading density

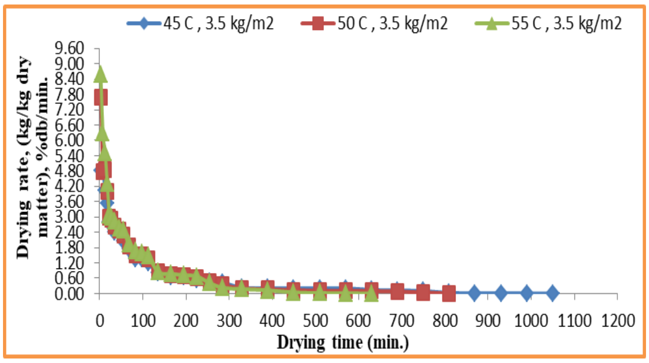

Chart. 4 Variation of drying rate with drying time at different temperature levels for 3.5 kg/m² loading density

The experimental moisture ratio and predicted moisture ratio vs. drying time curve fitting for treatment T_2 in different models are shown in Chart 6 to Chart 9.

The highest value of R^2 (0.9993) and lowest value of RMSE (0.0125) observed for treatment T_2 with Midilli model. Therefore, it could be concluded that though all four models suitably describe the drying behaviour of basil leaves but based on the highest R^2 value and lowest RMSE value, Midilli model was selected as the best model for prediction of the drying kinetic of basil leaves.

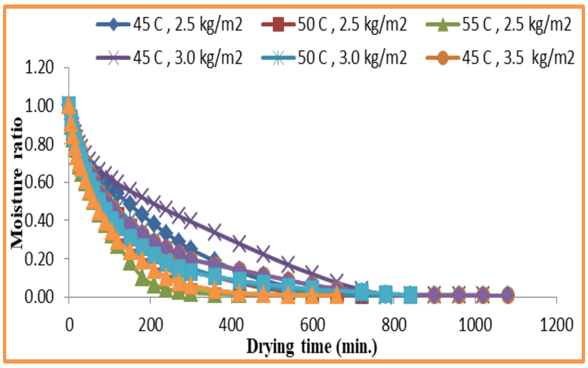

Chart. 5 Variation of moisture ratio with drying time at different drying treatments

3.5Effect on effective moisture diffusivity

Variation in effective moisture diffusivity of basil leaves with moisture content at different temperature and loading density is shown in Table 1. Effective moisture diffusivity values of basil leaves under various drying conditions were estimated in the range of 5.0×10^{-9} to 3.64×10^{-7} m²/s. The lowest value of effective moisture diffusivity was observed in treatment T_2 (5.0×10^{-9} m²/s), followed by the treatment of T_1 (3.75×10^{-9} m²/s).

The effective moisture diffusivity increased with increase in temperature and loading density. However, the moisture diffusivity further was higher at any level of moisture content at higher temperature level, resulting into shorter drying time.

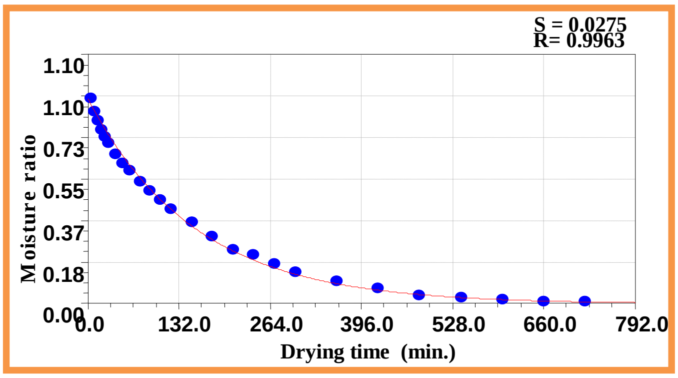

Chart. 6 Comparison of experimental and predicted moisture ratio Vs. drying time of basil leaves by Henderson and Pabis model for treatment T_2

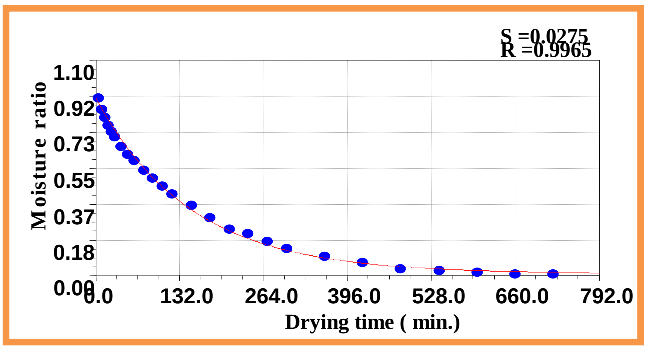

Chart. 7 Comparison of experimental and predicted moisture ratio Vs. drying time of basil leaves by Logarithmic model for treatment T_2

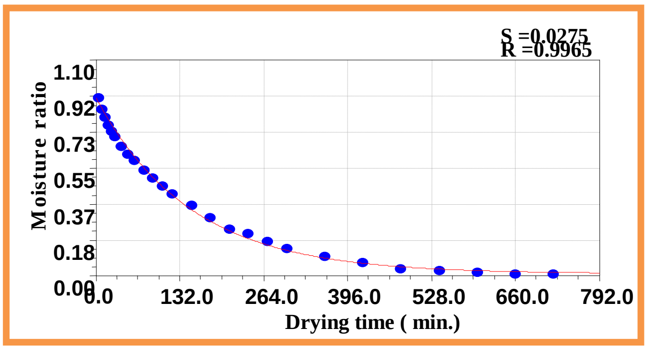

Chart. 7 Comparison of experimental and predicted moisture ratio Vs. drying time of basil leaves by Logarithmic model for treatment T_2

3.6Effect on activation energy

Variation in activation energy of basil leaves with moisture content at different temperature and loading density is shown in Table 1. The highest activation energy was observed under the treatment T_6 was noted to be 44.71 kJ/mol, followed by the treatment of T_2 with activation energy of 43.98 kJ/mol. The lowest value of activation energy among the treatments was noted to be 42.63 kJ/mol for the treatment T_5.

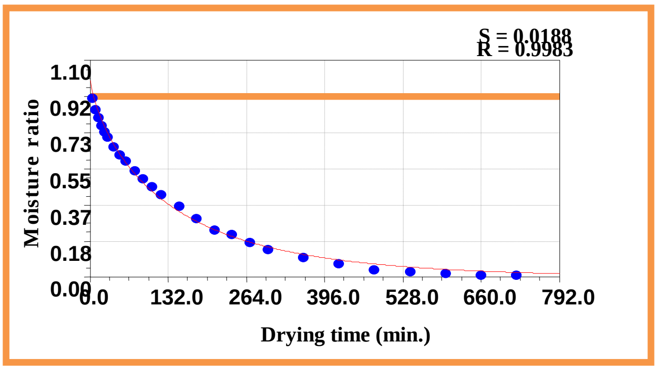

Chart. 8 Comparison of experimental and predicted moisture ratio Vs. drying time of basil leaves by Page model for treatment T_2

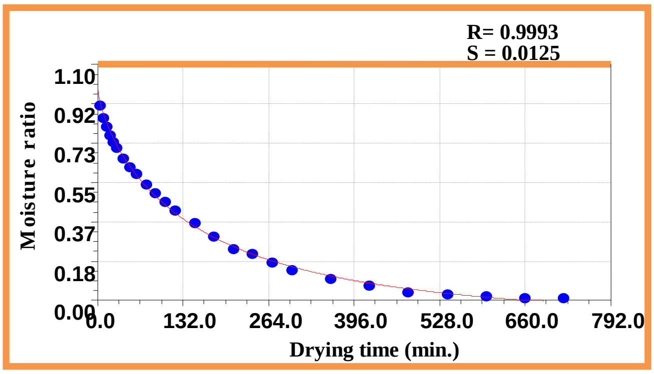

Chart. 9 Comparison of experimental and predicted moisture ratio Vs. drying time of basil leaves by Midilli model for treatment T_2

3.7 Effect of temperature (T) and loading density (L) on protein content

The data recorded on protein content as influenced by tray drying treatments was graphically illustrated in Chart. 10. The data pertaining to protein content % levels of dried basil leaves showed decreasing trend with increasing temperature and loading density. The decreasing trend also found during storage period of 3 months. Initially (0 months) the maximum protein content (6.80%) was recorded in T_2 treatment and was at par with T_1 (6.75%). However, the protein content (6.61%) was recorded in treatment T_9, which was minimum. Similar decreasing trend was observed at all the levels of storage durations.

3.8Effect of temperature (T) and loading density (L) on carbohydrate content

The data recorded on carbohydrate content as influenced by tray drying treatments was graphically illustrated in Chart. 11 Carbohydrate content (%) levels of dried basil leaves showed increasing trend with decreasing temperature and loading density. The decreasing trend also found during storage period of 3 months. Initially (0 months) the maximum carbohydrate content (7.32%) was recorded in T_2 treatment and was at par with T_3 (7.31%). However, the carbohydrate content (7.19%) was recorded in treatment T_9, which minimum. Similar decreasing trend was also observed at all the levels of storage durations.

Table 1 Effective moisture diffusivity and activation energy at experimental drying conditions

Treatment	Effective moisture diffusivity (m^2/s)	Activation energy (kJ/mol)
T_1	3.75×10^{-9}	43.37
T_2	5.0×10^{-9}	43.98
T_3	7.09×10^{-7}	43.31
T_4	3.54×10^{-8}	42.78
T_5	7.62×10^{-7}	42.63
T_6	4.17×10^{-9}	44.71
T_7	1.7×10^{-9}	43.58
T_8	3.16×10^{-8}	43.48
T_9	3.64×10^{-7}	43.49

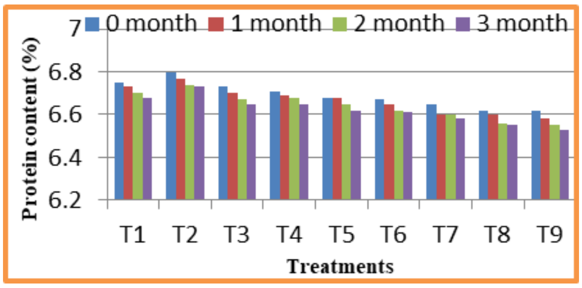

Chart. 10 Effect of temperature and loading density on protein content (%) of dehydrated basil leaves during storage

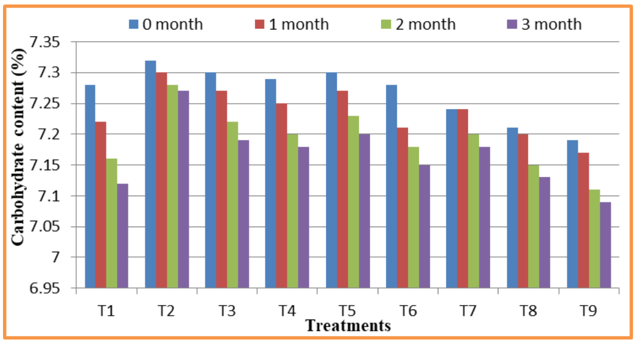

Chart. 11 Effect of temperature and loading density on carbohydrate content (%) of dehydrated basil leaves during storages

3.9 Effect of temperature (T) and loading density (L) on ash content

The data recorded on ash content as influenced by tray drying treatments was graphically illustrated in Chart. 12. Ash content (%) levels of dried basil leaves showed increasing trend with increasing temperature and loading density. Initially the maximum ash content (13.86%) found in T_4 which was at par with treatment T_3 (13.76%). However, the lowest ash content was recorded in treatment T_7 (13.01%).

3.10 Effect of temperature (T) and loading density (L) on coliform count (CFU/g)

The dehydrated sample obtained by different loading density of 2.5, 3.0 and 3.5 kg/m^2 at different temperatures. It is clear that loading density and different temperature did not affect much too coliform count (CFU/g).

3.11 Effect of temperature (T) and loading density (L) on rehydration ratio

The data recorded on rehydration ratio as influenced by tray drying treatments was graphically illustrated in Chart.13. The data pertaining to rehydration ratio of dried basil leaves showed an increasing trend with increasing temperature and loading density. But it showed a decreasing trend during storage period. Initially (0 months) maximum rehydration ratio was recorded in T_2 (6.21) treatment which was followed by T_6 (6.02). However, the lowest rehydration ratio was recorded in treatment T_5 (5.45). Similar decreasing trend was observed at all the levels of storage intervals.

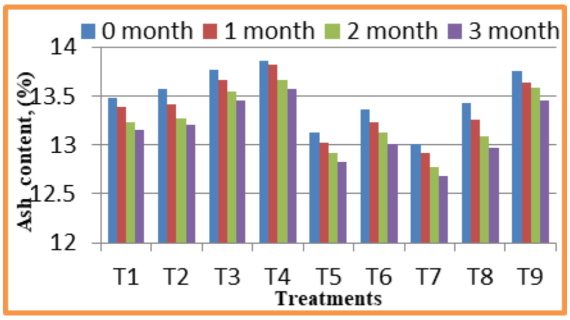

Chart. 12 Effect of temperature and loading density on ash content (%) of dehydrated basil leaves during storage

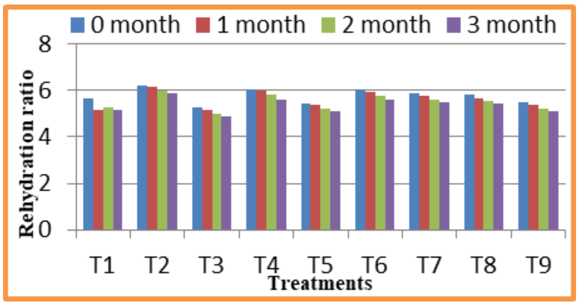

Chart. 13 Effect of temperature and loading density on rehydration ratio of dehydrated basil leaves during storage

3.12 Organoleptic quality

Organoleptic quality like colour, taste, flavour and overall acceptability of dehydrated as well as rehydrated basil leaves, was evaluated by panel of judges during 1 to 3 months of storage at 1 months interval during the experiment. The overall acceptability score (out of 9 points) of dehydrated as well as rehydrated basil leaves found best on colour, taste and flavour by various treatments during the storage period are furnished in depicted in Chart. 14. Panels of judges preferred the colour, taste and flavour score (7.9) of dehydrated as well as rehydrated basil leaves in treatment T_2.

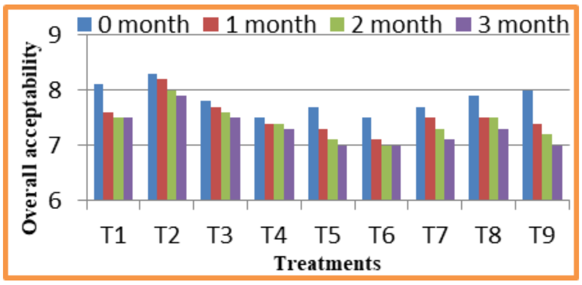

Chart. 14 Effect of temperature and loading density on overall acceptability of dehydrated basil leaves during storage

4. CONCLUSION

On the basis of experimental results and data analysis following conclusion could be drawn.

1. As the temperature increased and decreased loading density, increased the drying rate and decreased the drying time.
2. The whole drying process fresh basil leaves took place in falling rate period only and the average drying rate increased with increased temperature and loading density.
3. Midilli model was found best fitted drying model to describe the drying behaviours of basil leaves most precisely as R^2 value was highest (0.9993) as well as least RMSE (0.0125) as compared to other drying models.
4. Effective diffusivity (5.0×10^{-9} m²/s to 3.64×10^{-7} m²/s) increased with increasing temperature and loading density while activation energy (44.71 kJ/mol to 42.63 kJ/mol) decreased with increasing temperature and loading density.
5. Product quality in term of protein content, carbohydrate content, ash content and coliform count was found to be acceptable in all tray drying in which T_2 treatment at 50°C and loading density at 2.5 kg/m² was founds better results such as 6.73%, 7.27%, 13.20% and Nil at 3 months storage periods.
6. Basil leaves dried with at temperature of 50°C for 2.5 kg/m² loading density produce best quality dehydrated basil leaves. The highest overall acceptability was founds to be 7.9.

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