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Original Research Article

Thin Layer Drying Kinetics Modelling of Curry Leaves (*Murraya koenigii L.)* in Cabinet Dryer

Arjun Ghimire[1] and Nirajan Magar[2]*
[1]Department of Food Technology, Central Campus of Technology, Dharan, Sunsari, Nepal
[2]Dharan Multiple Campus, Dharan, Sunsari, Nepal
***Corresponding Author:** Arjun Ghimire, Lecturer, Department of Food Technology, Central Campus of Technology, Dharan, Nepal *E-mail: arzunghimire@gmail.com*

Abstract:

Curry leaves (*Murraya koenigii L.*) are the sweet smelling leaves of small tree of Rutaceae family native to South-west Asia. In this study, the effect of temperatures (50, 55 and 60^{0}C) on the drying of curry leaves was investigated. The experimental data were fitted to six thin layer mathematical models (Newton, Page, Handerson and Pabis, logarithmic, two-term exponential and Midilli et al). The models were evaluated in terms of coefficient of determination (R^2), chi square ($\chi 2$) and root mean square error (RMSE). The Midilli et al model was best fitted to the experimental data of all the models evaluated. The effective diffusivity was calculated using Fick's diffusion equation, and the value varied from 2.07×10^{-12} m^2/s to 2.643×10^{-12} m^2/s. The activation energy and the diffusivity constant were found to be 21.808 kJ/mol and $4.667\times10^{-8}$$m^2$/s respectively.

Keywords: Drying kinetics; *Murraya koenigii*; thin layer model; mathematical modelling

Introduction

Curry leaves are a popular leaf-spice used in very small quantities for their distinct aroma due to the presence of volatile oil and their ability to improve digestion. In the southern parts of India, curry leaves are mainly used to provide flavour to the curries, pickles, chutneys, soups, butter milk, south Indian *sambar* as well as to non-vegetarian items. In addition to food value, they add taste and smell to the foods. The leaves retain their flavour after drying and hence are marketed both in fresh and dried forms (Khatoon et al, 2011). Physical and biochemical changes that occur during drying seem to affect the quality of dehydrated product. The proper control of these reactions ensures that the dried product has a high nutritional value and a significantly extended shelf life. It is, therefore, essential to model and study the drying characteristics of food products in order to predict suitable drying conditions as part of process control and in the design and manufacture of dryers (Akonor and Amankwah, 2012). The objectives of the present research were to study the effects of temperature on the drying characteristics of curry leaves, determine a suitable thin layer mathematical model that describes its drying behaviour and evaluate the corresponding diffusivity and activation energy.

Materials and Methods

Sample preparation and drying of curry leaves

Fresh curry leaves were plucked from the different localities of Dharan sub- metropolitan city and winnowed to remove adhered dust and foreign materials. Three different lots of fresh curry leaves each weighing 50g were used for drying at 50, 55 and 60^{0}C in a cabinet dryer till constant weight was obtained.

Drying curves were obtained by plotting moisture ratio against drying time and drying rate against free moisture content,

Modelling of the drying process

The moisture ratio was calculated using equation (1) as modified by Roberts *et al.*, 2008:

$$MR = \frac{M}{M_o} \quad \text{..........(1)}$$

where MR is the moisture ratio, M is the moisture content at time *t* of the drying process (g/g dry solid) and M_o is the initial moisture content (g/g dry solid). The drying curves were fitted by means of six different moisture ratio models that are widely used in most food and biological materials as shown in **Table 1:**

Table 1. Mathematical models applied to the drying curves

Model name	Mathematical Equation	References
Newton	MR = exp (-kt)	Ceylan, 2007; Guine et al, 2011
Page	MR = exp ($-kt^n$)	Ceylan, 2007; Guine et al, 2011
Henderson and Pabis	MR = a exp (-kt)	Ceylan, 2007; Guine et al, 2011
Logarithmic	MR = a exp (-kt) + c	Ceylan, 2007; Guine et al, 2011
Two-Term exponential	MR = ae^{-kt} + $(1-a)e^{-kat}$	Saeed et al, 2008
Midilli et al.	MR = a exp ($-kt^n$) + bt	Midilli et al, *2002*

Determination of effective moisture diffusivity and activation energy

Fick's second law of diffusion was used to evaluate the effective diffusivity of curry leaves because all of the samples showed a falling rate period in their drying characteristics. Samples used in the present study were analysed in slab geometry form; thus, the effective diffusivity of the samples was determined by Equation 2 by linear fitting as:

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

Where D_{eff}, L and t are the effective moisture diffusivity (m^2/s), thin layer thickness (m) and time (h) respectively.

The Arrhenius equation (Equation 3) was used to describe the relationship between the effective diffusivity and drying temperature as given by Roberts et al*,* (2008) by linear fitting as:

$$\ln(D_{eff}) = \ln(D_o) - \frac{E_a}{R}\left(\frac{1}{T}\right) \quad \text{......... (3)}$$

Where, D_o is the diffusivity constant (m^2/s), E_a is the activation energy (KJ mol^{-1}), R is the universal gas constant (8.314 J $mol^{-1}K$), and T is the absolute air temperature (K).

Data analysis

Non- linear regression analysis was performed using Microsoft Excel 2013. The coefficient of determination (R^2), chi- square (χ^2) and root mean square error (RMSE) of each mathematical model was calculated and a suitable drying model was chosen based on the goodness of fit with highest value of R^2 and lowest value of RMSE and χ^2. (Sacilik et al, 2006; Hassan-Beygi et al, 2009; Sobukola, 2009).

Results and Discussion

Drying Curves

The drying curves of curry leaves at different temperatures are shown in Figure 1. The drying temperature significantly affected the drying rate of curry

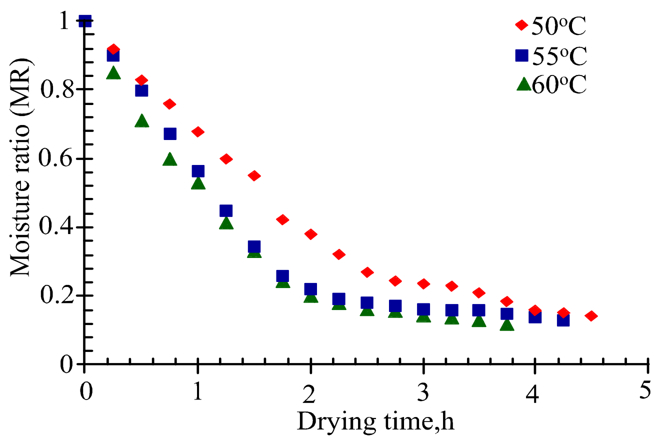

Fig 1. Drying curve of curry leaves dried at different temperatures

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leaves. This finding is in agreement with those obtained by Vega-Galvez et al, (2012), who studied the effect of temperature and air velocity on the drying kinetics of apple slices, and found that the drying rate of apples increased with increase in temperature. At high drying temperatures, the drying rate is faster due to the excitation of molecules in the samples (Jamali et al, 2006). As the temperature increases, water molecules inside the sample move faster, which increases the distance between molecules and hence, reduces the attractive forces between them. Thus, an increase in the drying temperature increases the amount of moisture removed from the samples.

From Figure 2, it was clear that drying rate of curry leaves falls in falling rate period. That means, critical moisture content was not found on the drying rate curve. The drying rate was decreased and less moisture was available at the surface to evaporate. The food surface is no longer saturated with moisture. That means, a layer of water on the surface of product disappears and hence falling rate starts.

Mathematical modelling

The moisture ratio (MR) was calculated using Equation 1, and regression analysis was performed using Microsoft Excel.

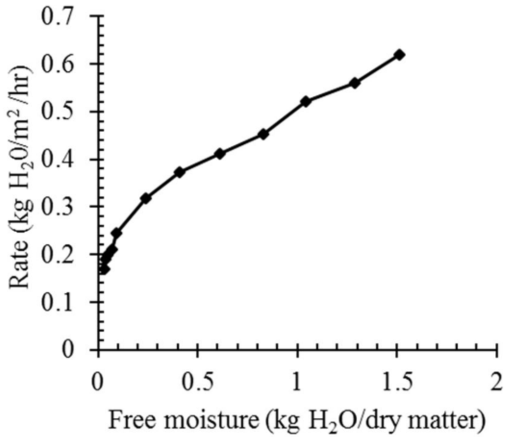

Fig 2. Drying rate curve of curry leaves showing drying rate as a function of moisture content

Table 2 shows the calculated data for the selected thin layer drying model. Compared to other mathematical models, the Midilli et al, model was the best model for all of the drying temperatures because the lowest RMSE and χ^2 were observed with highest R^2 values (Table 3). The results were confirmed by plotting the graph of the experimental MR versus the predicted MR (Figure 3). All of the R^2 values were greater than 0.99, which indicates that the fit was good

Table 2. Mathematical drying model constants

T (°C)	Model name	Model constants
50	Newton	k=0.461072
	Page	n=1.09307, k=0.428526
	Logarithmic	a=1.028256, c=0.011335, k=0.492751
	Two-term exponential	a=1.000001, k=0.456173
	Midilli et al.	a=0.990611, n=1.322927, k=0.43904, b=0.025242
55	Newton	k=0.62596
	Page	n=1.029234, k=0.616132
	Logarithmic	a=0.9905, c=0.0738, k=0.7995
	Two-term exponential	a=1.0000001, k=0.62596
	Midilli et al.	a=0.993631, n=1.437336, k=0.666903, b=0.03571
60	Newton	k=0.700233
	Page	n=0.98835, k=0.703983
	Logarithmic	a=0.971249, c=0.053422, k=0.816247
	Two-term exponential	a=1, k=0.700233
	Midilli et al.	a=0.98748, n=1.211065, k=0.758577, b=0.026085

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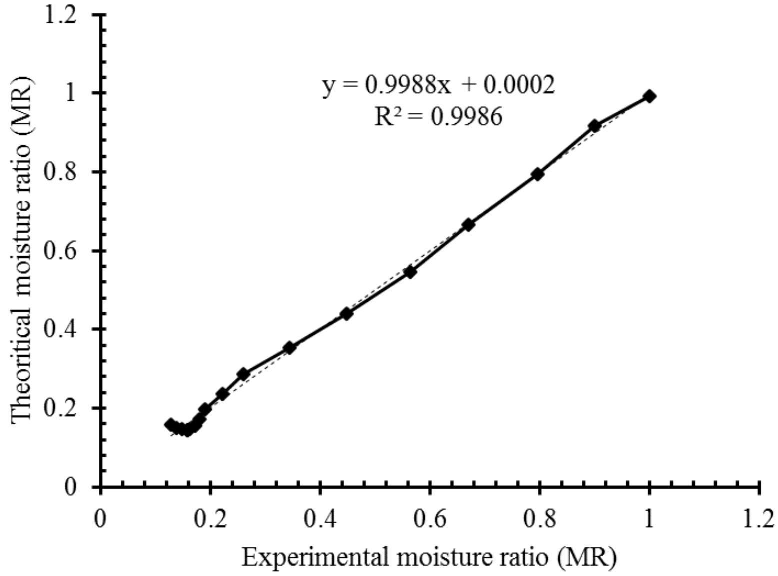

Fig.3. Calculated MR vs actual MR for the Midilli *et al.* model at 55°C

Table 3. Statistical results for thin layer mathematical modelling at different drying temperatures

T (°C)	Model name	RMSE	χ^2	R^2
50	Newton	0.029632	0.000927	0.9954
	Page	0.02518	0.0007	0.9960
	Logarithmic	0.026454	0.0008	0.9953
	Two-term exponential	0.0294	0.0009	0.9953
	Midilli et al.	0.0168	0.0003	0.9980
55	Newton	0.045597	0.002	0.987343
	Page	0.045365	0.002315	0.9875
	Logarithmic	0.0374	0.0084	0.991
	Two-term exponential	0.045597	0.00233	0.98734
	Midilli et al.	0.01445	0.00094	0.9986
60	Newton	0.028641	0.000875	0.9947
	Page	0.02858	0.000934	0.994754
	Logarithmic	0.0243	0.00073	0.9968
	Two-term exponential	0.028641	0.000937	0.99478
	Midilli et al.	0.016042	0.000343	0.999269

Effective Diffusivity (D_{eff}) and Activation energy (E_a)

As the drying temperature increased, the value of effective diffusivity also increased. Samples dried at 50 °C presented the lowest D_{eff}, which was 2.07×10^{-12} m²/s. These results were calculated using equation (2) and found to be within the range of effective diffusivities of agriculture products reported by several researchers (Table 4).

Table 4. Effective diffusivities of dried curry leaves and other agriculture products.

Agriculture Material	Effective Diffusivity, D_{eff} (m^2/s)	References
Curry leaves (50°C)	2.07×10^{-12}	Current work
Curry leaves (55°C)	2.233×10^{-12}	Current work
Curry leaves (60°C)	2.643×10^{-12}	Current work
Apple	$0.483 \times 10^{-10} – 2.019 \times 10^{-10}$	Kaya et al., 2007
Celery	$3.43 \times 10^{-11} – 1.714 \times 10^{-10}$	Evin, 2012
Cocoa	$8.01 \times 10^{-11} – 4.84 \times 10^{-10}$	Hii *et al., 2009*

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The estimated diffusivity constant, D_o, and activation energy, E_a, were 4.667×10^{-8} m^2/s and 21.808 kJ/mol, respectively. These values were determined using the relationship shown in Figure 4. The value of E_a was within the range of values reported in previous studies, which varied from 12.32 kJ/mol to 51.26 kJ/mol (Hii et al, 2009; Senadeera et al, 2003).

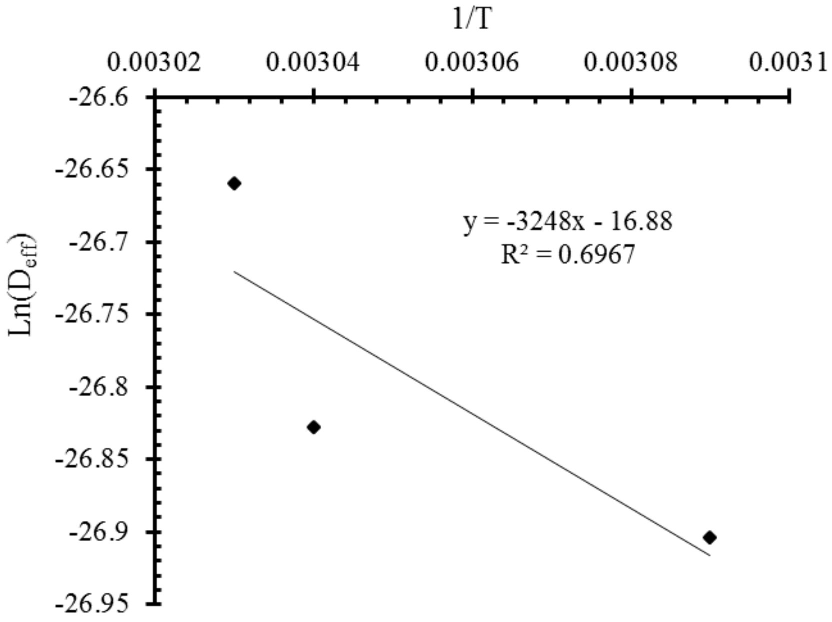

Fig 4: Plot of ln D_{eff} vs. 1/T during the cabinet drying of curry leaves

Conclusion

The drying of curry leaves was carried out at three different drying temperatures (50, 55 and 60 ^{0}C) in a cabinet dryer. Based on the present results, the drying temperature significantly affected the drying rate of curry leaves. According to the R2, χ2, and RMSE values, the Midilli et al. model was best fitted to the experimental data. The effective diffusivities varied from 2.07×10^{-12} m^2/s to 2.64×10^{-12} m^2/s. The diffusivity constant and activation energy were estimated using the Arrhenius equation, and the values were found to be 4.667×10-8 m^2/s and 21.808 kJ/mol respectively.

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