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MATHEMATICAL MODELLING OF POTASSIUM META-BISULPHITE TREATED MANGO (*Mangifera indica*) SLICES cv *Dasheri*

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ABSTRACT

Fresh and ripe mango (Mangifera indica) slices cv Dasheri were dehydrated in a cabinet dryer at drying air temperatures of 50, 60, and 70 ºC *at a slice thickness of 5 mm. Before dehydration, the mango slices were pre-treated with potassium meta-bisulphite (KMS) at three levels (0.5 %, 1.0 %, and 1.5 % KMS, respectively). Five semi-theoretical and empirical thin-layer drying models (Newton [Lewis], Logarithmic, Demir et al. 2004, Henderson & Pabis, and Wang & Singh) were employed to select the best model that describes the drying process. Moisture diffusivity and activation energy of the mango slices were also evaluated. It was observed that the drying took place in the falling rate period. Demir et al. 2004 and Logarithmic models were found to satisfactorily describe the drying process of the mango slices using R^2, x^2, SSE, and RMSE as the criteria for selecting the best model. The mango slices' moisture diffusivity and activation energy range from 6.79 to 10.02×10-8 m2/s and 10.03 to 14.73 kJ/mol. Thus, KMS pre-treatment can minimise the mango slices' drying duration and drying cost.*

Keywords: Cabinet dryer; *Dasheri* mango; mathematical modelling; moisture diffusivity; activation energy.

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INTRODUCTION

Mango (*Mangifera indica*) is among the most cultivated fruits in the world. The fruit has an appealing fragrance, a sweet taste, and a pleasant flavour (Tharanathan, Yashoda, & Prabha, 2006). In addition, it is rich in antioxidants and vitamins such as pigment carotenoids, polyphenols, omega-3 and -6 polyunsaturated fatty acids (Jha, Jaiswal *et al*., 2010). Thus, it contains 1-3 times recommended daily intake (RDI) of Vitamin C and *β*-carotene (Jha, Narsaiah *et al*., 2010). India and Nigeria are among the top ten mango-producing countries globally, with an annual production estimated at around 19,506,000 and 935,954 MT, respectively (FAO, 2017). The global production of mango stands at 50,681,147 MT. However, unfortunately, the export volume is less than 10% of the total output, and most of which is used for table purposes instead of being processed for commercial purposes (FAO, 2017; Vijayanand, Deepu, & Kulkarni, 2013). India dominates the world trade of processed

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mango, though hardly 1-2% of the total mango produced in India is processed. However, only 20% of the processed mango products are being exported, out of which mango pulp accounts for 80% of the exported products. The post-harvest losses of mango were estimated at around 25 – 40% (Vijayanand *et al*., 2013)**.** Similarly, Nigeria is the leading producer in Africa and eighth globally, but not among the top ten mango exporting countries. Thus, the situation of mango is worse compared to India. The post-harvest losses reach up to 50%, mainly due to poor post-harvest practices and environmental factors such as high temperature and relative humidity. Thus, the country is lagging in utilising and exporting fresh or processed mango. Mango processing is done locally at a meagre scale and confined to only mango juice (Alaka, Aina, & Falade, 2003; Saave, 2011).

Considering the facts above and the problems of perishability and seasonality, the fruit is yet to realise its maximum potential as an export-oriented commodity in most major producing countries, India and Nigeria. Therefore, the mango fruit must be quickly stabilised and processed after harvest. This is because the mango has a short production season, which causes a glut during the season, a high amount of post-harvest losses, and underutilisation. The mango processing would also help avoid market glut during its season stabilise its price, thereby ensuring income security to farmers and bringing nutritional security to society in general (Akoy, 2014; Korbel *et al*., 2013; P. S. Kumar & Sagar, 2014). In addition, the demand for mango in the global market is growing at a high rate, especially in the temperate countries, because of social changes, promotion of fruit trade in developing countries, and availability of international air cargo due to lack of encouragement from the government (Tharanathan *et al*., 2006; Vijayanand *et al*., 2013; Yusuf & Salau, 2007).

Dehydration appears to be one of the most promising and widely used preservation techniques to extend shelf life, reduce weight, minimise transportation costs, and smaller space for storage of food products. It is also suitable for developing countries where it is uncommon to establish the most sophisticated food preservation techniques because of an erratic power supply and huge capital outlay. Conversely, dehydration significantly impacts the stability of various health-promoting antioxidants components in processed products (Akoy, 2014; Alakali, Kucha, & Ariahu, 2010; Doymaz & Kocayigit, 2011; Korbel *et al*., 2013; P. S. Kumar & Sagar, 2014). Dehydration is a method of industrial preservation in which hot air reduces the water content and water activity of fruits and vegetables to reduce biochemical, chemical, and microbiological degradation (Doymaz & İsmail, 2010; Doymaz & Kocayigit, 2012; Kadam, Goyal, Singh, & Gupta, 2011; Owa, Agbetoye, & Akinbamowo, 2015). Pre-treatment drying should be employed to dry food products as quickly as possible and retain the product's quality and minimise energy costs. Additionally, the use of pre-treatments can help increase drying efficiency. This may be by increasing the drying rate by removing the surface resistance and relaxing the tissue structure of fruits and vegetables. Pre-treatment s can also prevent loss of colour by inactivating enzymes and yield a good quality dried product (Alakali *et al*., 2010; Azoubel, De Oliveira, Araújo, Silva, & Park, 2008; Doymaz & Kocayigit, 2012).

According to Erbay and Icier (2010), thin layer drying equations may be theoretical, semi-theoretical, and empirical models. The theoretical models solely consider the product's internal resistance to moisture

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transfer; they clearly describe its drying behaviour and can be applied to any process situation. They do, however, include several assumptions that result in significant inaccuracies. First, Fick's second law of diffusion is the basis for the most extensively used theoretical models. The other two models solely consider the product's exterior resistance to moisture transfer to the air. Fick's second law and adaptations of its simpler versions are the most common semi-theoretical models (other semi-theoretical models are generated through analogies with Newton's law of cooling). They are more accessible and need fewer assumptions due to experimental data, but they are only valid within the process conditions that have been applied. On the other hand, the empirical models also have similar characteristics to semi-theoretical models. They strongly depend on the experimental conditions and give limited information about the drying behaviours of the product (Bruce, 1985; Fortes & Okos, 1981; Henderson, 1974; Keey, 1972; Özdemir & Devres, 1999; Parry, 1985; Parti, 1993; Suarez, Viollaz, & Chirife, 1980; Whitaker, Barre, & Hamdy, 1969).

Thus, hot air dehydration of mango slices using potassium meta-bisulphite as a chemical pre-treatment agent was undertaken to obtain a mathematical model for the characteristics of the mango slices. Furthermore, the mango slices' activation energy and moisture diffusivity were also evaluated.

MATERIAL AND METHODS

Experimental apparatus

The mango slices' initial moisture content determination and drying were conducted in a hot air oven [Make: Swastika Bio Remedies (P) Ltd, Ambala Cantt, India; Model: Alpine]. The dryer mainly consists of three basic units: an air supply unit, electrical heaters controlling drying air temperature, and the drying chamber. It has four shelves for placing samples, a double-walled door with an asbestos gasket on the inner side, a double-walled drying chamber with high-grade insulation to prevent heat loss, mild steel external case, a control panel at the bottom of the oven housing with a main ON/OFF switch, indicator lamp, and temperature control knob. The oven works on an alternating current of 220 volts 50 Hertz of a power supply. It has a temperature range of 50 to 300 °C and accuracy of ±1°C. An electronic balance (Make: National Scales, ISO 9001: 2008 Company; Model: Apolo) of 0.001 g sensitivity was used to record the weight of mango slices during the drying. The scale has a maximum capacity, minimum capacity, and error of 600 g, 200 mg, and ±10 mg, respectively. A hot plate (Make: Gupta Scientific Industries, Ambala Cantt. India; Model: Perfit) was used to determine the rehydration ratio of the dehydrated mango slices.

Experimental material

Fresh mangoes (*Mangifera Indica* cv. *Dasheri*) were purchased from local fruit sellers in Allahabad, India. The mangoes were washed, air-dried, and then kept at 4 °C until the experiment was conducted.

Sample preparation and pre-treatment

The mangoes were removed from the refrigerator before experimenting and kept at ambient temperature for 2 hours to achieve equilibrium. The mango was then sliced into rectangular slabs of an average thickness of 5 mm each. 3 – 5 slices of the mango were placed on a Petri dish and then dried. The drying was a thin layer in nature as the thickness of the mango slices was less than 15 cm. The dried samples were kept in polythene bags and stored under dry and ambient conditions until further experiments. The

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samples were treated by dipping the mango slices in Potassium Meta-bisulphite (KMS) of 0.5 g/100 ml, 1.0 g/100 ml, and 1.5 g/100 ml solutions, respectively, at room temperature for 5 min prior to drying. Mango slices dipped in an equal mass of water for 5 min were used to control.

Experimental Procedure

Initial moisture content

The initial moisture content of the sample was determined according to the AOAC (2000) method by drying at 130 ℃ for 2 hours in a cabinet dryer. The initial moisture content was calculated as follows:

$$MC_{db} = \left(\frac{WM}{DM}\right) \times 100 \qquad (1)$$

Where MC_{db} is the moisture content % (dry basis), *WM* is the mass of wet matter (*g*), and DM is the mass of dry matter (*g*).

Drying of the mango slices

The pre-treated mango slices were placed on Petri dishes, weighed, and subsequently placed on a drying tray and loaded into the dryer. The dryer was operated unloaded for 30 min to achieve a steady-state condition. The drying was conducted at 50, 60, and 70 ℃. The weight loss of the sample was recorded at an interval of 30 min up to equilibrium moisture content. The equilibrium moisture content of the sample was achieved when three consecutive readings gave the same value; that is to say, there was no reduction in the weight of the sample. The whole experiment was replicated three times for each temperature and pre-treatment level.

Mathematical modelling

The drying data was used to calculate the sample's drying ratio at different temperatures and pre-treatments, then fitted into five semi-theoretical and empirical thin-layer drying models (Table 1). The moisture ratio was computed from the relationship below (Bhattacharya, Srivastav, & Mishra, 2013):

$$MR = \frac{M_t - M_e}{M_i - M_e} \qquad (2)$$

Where *MR*, M_i, M_t, and M_e are moisture ratio, initial moisture content, moisture content at any given time, and equilibrium moisture content, respectively.

The values of M_e are relatively small compared to M_i and M_t; hence the error involved in the simplification by assuming that M_e is equal to zero is negligible; thus, the moisture ratio would be calculated as (Hashim, Daniel, & Rahaman, 2014):

$$MR = \frac{M_t}{M_i} \qquad (3)$$

The drying rate of the samples was calculated according to Chakraverty (1981) as:

$$DR = \frac{W}{t \times \left(\frac{M_{bd}}{100}\right)} \qquad (4)$$

Where *DR* is the drying rate (g of water/min/100 g b.d material), *W* is the amount of water removed (*g*), M_{bd} is the weight of bone-dry material (*g*), and t is the time (min).

The thin-layer drying models tested were Newton (Lewis), Logarithmic, Demir *et al.* 2004, Henderson & Pabis, and Wang & Singh (Table 1). A graph of moisture ratio was plotted against the drying time, from which the drying constant (k) and the various other parameters of the above models were determined.

Activation energy

The activation energy was calculated using the Arrhenius type equation (Arora, Bharti, & Sehgal, 2006). The diffusivity coefficient at different temperatures is often found to be

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well predicted by the Arrhenius equation given by:

$$D_{eff} = D_o exp\left(\frac{-E_a}{R(T+273.15)}\right) \quad (5)$$

Where D_{eff} is the effective diffusivity coefficient (m^2/s), D_o is the maximum diffusion coefficient (m^2/s), E_a is the activation energy (kJ/mol), T is the Temperature (℃), and R (8.314) is the Gas constant ($kJ/mol.K$). Eq. 5 was simplified as follows:

$$\ln(D_{eff}) = \frac{-E_a}{R(T+273.15)} + \ln D_o \quad (6)$$

A plot of $\ln(D_{eff})$ against $1/(T+273.15)$ produced a straight-line graph with $-E_a/R$ as the slope and $\ln(D_o)$ as the intercept, from which the activation energy and the Arrhenius constants were evaluated.

Moisture diffusivity

Fick's second law is widely used to describe the diffusion mechanism in drying solid food materials (Crank, 1975). In this study, the mango slices were assumed to be infinite slabs, and drying occurred mainly in the falling rate period. Thus, the effective moisture diffusivity (D_{eff}) within infinite slabs can be estimated from the below equation:

$$MR = \frac{8}{\pi^2}\sum_{n=0}^{\infty}\frac{1}{(2n+1)^2} exp\left[-(2n+1)^2\frac{D_{eff}\pi^2 t}{4L^2}\right] \quad (7)$$

For long drying time, Eq. 7 was modified and expressed according to Darvishi, Azadbakht, Rezaeiasl, and Farhang (2013) as follows:

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

Where MR is the moisture ratio (Dimensionless), D_{eff} is the effective moisture diffusivity (m^2/s), t is the drying time (min), and L is the thickness of the sample (m). Eq. 8 was simplified as below:

$$\ln(MR) = \frac{\pi^2 D_{eff}}{4L^2}t + \ln\left(\frac{8}{\pi^2}\right) \quad (9)$$

The effective moisture diffusivity was determined according to N. Kumar, Sarkar, and Sharma (2012) by plotting a graph of experimental drying data in terms of $\ln(MR)$ versus drying time t. The graph gives a straight line with a slope of $\frac{D_{eff}}{4L^2}$. The thickness of mango slices and slope were used to calculate the effective moisture diffusivity of the samples.

Statistical analysis

Four statistical tools were used to examine the fitness of the models to the drying data. The tools are Chi-square (x^2) (Midilli *et al*., 2002) or Mean Square Error (MSE) (Saeed, Sopian, & Zainol Abidin, 2008), Coefficient of determination (R^2) (Taheri-Garavand, Rafiee, & Keyhani, 2011), Sum of Squares Error (SSE) (Hashim *et al*., 2014) and Root Mean Square Error (RMSE) (Mahdhaoui, Mechlouch, Mahjoubi, Zahafi, & Brahim, 2013). Analysis of Variance (ANOVA) was employed to analyse the results using XLSTAT statistical software (2015 version, Addinsoft Inc., USA). Tukey, a pairwise comparison test, was used to compare the means of each treatment (p<0.05).

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$$\chi^2 = \frac{\sum_{i=1}^{N}\left(MR_{exp,i} - MR_{pre,i}\right)^2}{N-n} \quad (10)$$

$$R^2 = 1 - \left[\frac{\sum_{i=1}^{n}\left(MR_{pre,i} - MR_{exp,i}\right)^2}{\sum_{i=1}^{N}\left(MR_{pre} - MR_{exp,i}\right)^2}\right] \quad (11)$$

$$RMSE = \sqrt{\frac{\sum_{i=1}^{N}\left(MR_{pre,i} - MR_{exp,i}\right)^2}{N}} \quad (12)$$

$$SSE = \left[\frac{\sum_{i=1}^{N}\left(MR_{exp,i} - MR_{pre,i}\right)^2}{N}\right] \quad (13)$$

Where $MR_{exp,i}$, $MR_{pre,i}$, N, and n are the *ith* experimental moisture ratio, *ith* predicted moisture ratio, number of observations, and number of constant, respectively.

RESULTS AND DISCUSSION

Drying characteristics of the mango slices

The initial moisture content of the mango fruit was determined using the oven drying method, and it was found to be 450 % dry basis. The control and the treated mango slices were dried in a tray dryer at 50, 60, and 70 ℃. The drying time and the final moisture content are shown in Table 2. Compared to the control and other treated samples, the mango slices pre-treated with 1 % KMS showed better final moisture content and relatively good drying time. Singh and Goyal (2012) reported a similar result for mango slices dried in a tunnel dryer. Generally, it was observed that the moisture content decreased continuously with drying time. Several other authors also find temperature as the main factor that influences the drying time of food products, such as drying of long pepper (Bhagyashree, Vanita, & Sneha, 2013), cocoa bean (Ndukwu, 2009), and African catfish (Omodara & Olaniyan, 2012).

Effect of pre-treatment on the drying time and final moisture content

The drying time increases with an increase in KMS pre-treatment level, as seen in T_2 and T_3 (Table 2); a similar trend was observed by Al-Amin, Hossain, and Iqbal (2015). This might be due to high moisture uptake at a high pre-treatment level. According to Al-Amin *et al*. (2015), KMS greatly influences drying time as it offers higher resistance to both heat and mass transfer, resulting in higher drying time as the KMS level increases. However, the final moisture content decreases with an increase in KMS level. Hence, KMS has a significant effect on drying time and the final moisture content of the product. The relationship between moisture content and drying time at various temperatures and pre-treatment levels shows a usual exponential trend which agrees with previous investigations such as drying of pre-treated banana slices (Abano & Sam-Amoah, 2011), convective drying of Osmo-dehydrated sapota slices (S. V. Gupta & Patil, 2014), modelling of air-dried bay leaves (Demir *et al*., 2004).

Mathematical modelling of the mango slices

Five thin layer drying models were used for the Hot Air Drying of Dasheri Mango slices to see which one was the best match. As a result, the collected experimental data were fitted into these models, and correlation parameters are shown in Tables 3, 4, and 5 below. Non-linear regression analysis was used to determine the statistical parameters at the various drying temperatures. At all the drying temperatures, Logarithmic and Demir *et al*. 2004 models excellently describe the drying kinetics of the mango slices as the values of coefficient of correlation (R^2) approach 1. In contrast, the Mean Square Error, Sum of Squares Error, and Root Mean Square Error values were close to zero. Previous works by numerous researchers

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found the logarithmic model as the model with the best fit in describing drying kinetics of food products, such as Abdul Rahman, Wahid, and Rahman (2015) for *Nephelium Lappaceum* (*Rambutan*), S. Gupta, Cox, and Abu-Ghannam (2011) for edible Irish brown seaweed, Radhika, Satyanarayana, and Rao (2011) for Finger Millet and Sridhar and Madhu (2015).

On the other hand, Demir *et al*. (2007) and Kaveh and Chayjan (2014) found the Demir *et al*. 2004 model to best describe the drying of green table olive and terebinth fruit. Newton (Lewis) and Henderson & Pabis models also described the drying kinetics of the mango slices with a good fit, while Wang & Singh is the model with the least fit. Thus, Logarithmic and Demir *et al.* 2004 models were found to describe the drying kinetics of the mango slices. Therefore, the Logarithmic and Demir *et al*. 2004 models were used to predict the moisture ratio of the mango slices dried in a hot air oven. Fig. 1 and 2 show the model's predicted and experimental moisture ratio at 60 ℃.

Effective moisture diffusivity

It can be seen from Table 6 that pre-treatment and temperature have a profound effect on the effective moisture diffusivity of the mango slices as diffusion rate is directly proportional to concentration gradient and surface area (Raees-ul Haq, Kumar, & Prasad, 2018). In terms of drying air temperature, it was observed that the mango slices had the highest effective moisture diffusion at a drying air temperature of 60 ℃. It was also examined that T_1 at 50 ℃ had the most elevated moisture diffusivity compared to all other samples in general. However, the pre-treatment and temperature influenced the moisture diffusion in the mango slices, especially at high pre-treatment levels; as shown in Table 6, the diffusion at T_3 increased as the temperature increased from 50 to 70 ℃. This was also observed by Al-Amin *et al*. (2015). A fluctuation was observed in the diffusion rate of the samples at the drying temperatures of 60 and 70 ℃. This might be because water evaporation per unit area is higher at low pre-treatment levels of KMS than those with high pre-treatment levels (Al-Amin *et al*., 2015). In addition, variation in material composition, structure, temperature, and moisture content also causes diffusivity disproportion (Zogzas, Maroulis, & Marinos-Kouris, 1996). Abano, Ma, Qu, and Teye (2011) observed similar moisture diffusivity values in KMS pre-treated garlic. However, the correlation coefficients indicate good fitness between the experimental and predicted values considering the high values of the R^2, especially at a drying air temperature of 50 ℃.

Activation energy

Activation energy is the minimum energy required or must be overcome for moisture diffusion inside the material (Thao and Noomhorm 2011). It was calculated by plotting a graph of $ln(D_{eff})$ against $1/(T+273.15)$ which produces a straight-line graph with $-E_a/R$ as the slope and $ln(D_o)$ as the intercept, it was observed that the activation energy of the mango slices had no definite pattern. The E_a values increase then decrease for control, T_1, T_2, and T_3, respectively (Table 7). This shows that pre-treatment affects the energy required to diffuse moisture within the mango slices. Higher activation energy indicates a higher sensitivity to the temperature of the diffusion coefficient (Corzo, Bracho, & Alvarez, 2008). Similar results were obtained by Corzo *et al*.

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(2008) for green and half-ripe mango slices (11.4 – 22.3 kJ mol^{-1} and 8.7 – 9.3 kJ mol^{-1} for green and half-ripe mango slices, respectively).

CONCLUSION

The temperature and potassium meta-bisulphite (KMS) pre-treatment had a noticeable effect on drying time and the final moisture content of the mango slices. The relationship between moisture content and drying time revealed a normal, exponential trend at various temperatures and pre-treatment levels. Thus, the drying took place under two falling rate periods. Also, the pre-treatment affected the drying rate of the mango slices at all the drying air temperatures, though the superior outcome was observed at a drying air temperature of 60℃.

In addition, the drying rates were higher at higher temperatures. However, the drying of the mango slices was described appropriately by Demir *et al.* 2004 and Logarithmic models for all the temperatures and pre-treatments. The effective moisture diffusivity and activation energy of the mango slices varies with regard to temperature and pre-treatment. In a nutshell, it can be recommended that optimum dehydration of the mango slices can be accomplished at a dehydration air temperature of 60 ℃ and KMS pre-treatment level of 1% using Demir *et al*. 2004 and Logarithmic models.

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APPENDICES

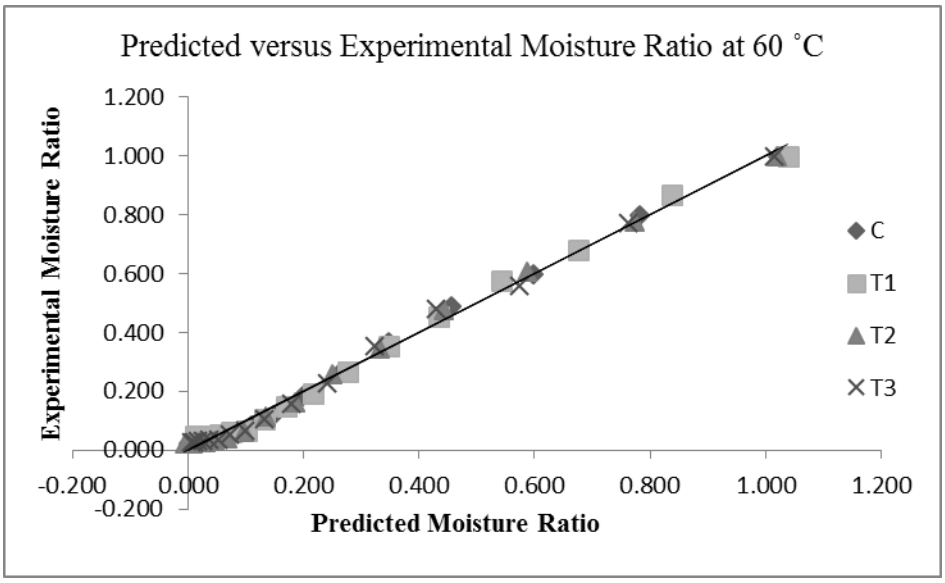

Figure 1 Predicted and experimental moisture ratio of Logarithmic model at 60 ℃

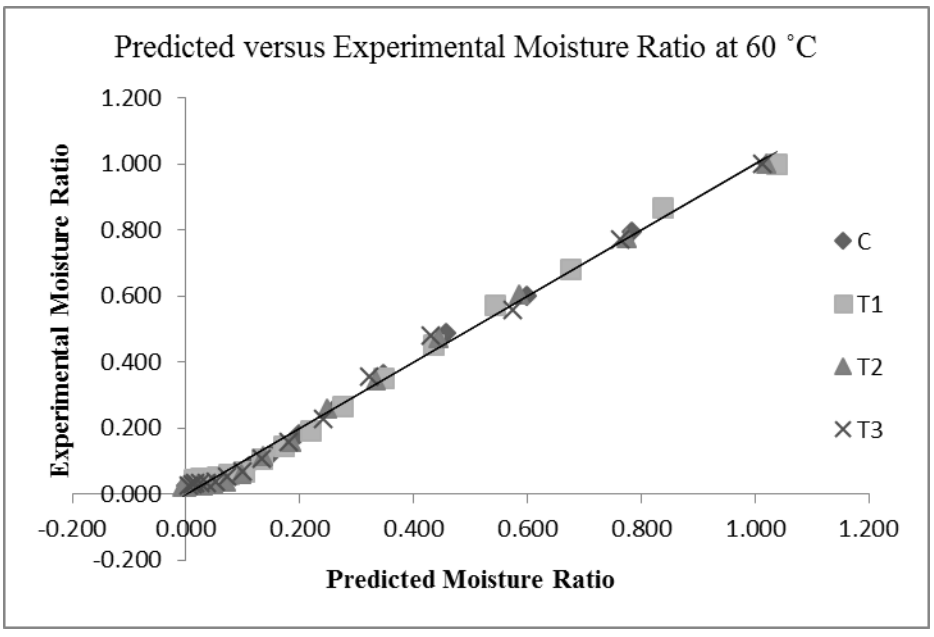

Figure 2 Predicted and experimental moisture ratio of Demir *et al.* 2004 model at 60 ℃

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Table 1: Thin-layer drying models

S/N	Model Name	Model	References
1	Newton (Lewis)	MR = *exp*(-kt)	(Demir, Gunhan, Yagcioglu, & Degirmencioglu, 2004; Lewis, 1921)
2	Logarithmic	MR = a *exp*(-kt) + c	(Erbay & Icier, 2010; Midilli, Kucuk, & Yapar, 2002)
3	Demir *et al*	MR = a *exp*[(-kt)]^n + b	(Demir, Gunhan, & Yagcioglu, 2007; Erbay & Icier, 2010)
4	Henderson & Pabis	MR = a *exp*(-kt)	(Hashim et al., 2014; Hee & Chong, 2015).
5	Wang & Singh	MR = 1+bt+at^2	(Saxena & Dash, 2015; Wang & Singh, 1978)

Table 2: Drying time and final moisture content of mango slices

Temperature (℃)	Pre-treatment	Drying Time (min)	Final Moisture Content % (d.b.)
50	Control	450a	13.14da
	T_1	390b	8.52db
	T_2	660c	6.18dc
	T_3	690d	10.43df
60	Control	450ab	10.98ea
	T_1	450ac	21.23eb
	T_2	450ad	9.33ec
	T_3	450ae	12.57ef
70	Control	420ba	23.10da
	T_1	420bc	31.70de
	T_2	480bd	6.64df
	T_3	540be	5.52dg

T_1= 0.5 % KMS, T_2= 1 % KMS, T_3=1.5 % KMS, d.b = dry basis. Different lowercase letters indicate significant difference (p<0.05).

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Table 3: Correlation parameters and model constants for the selected thin layer drying models at 50 ℃

Model Name	Pre-treatment	Constants				R^2	SSE	MSE	RMSE
Newton	Control	k = 0.0082				0.9978	0.0052	0.0003	0.0187
	T_1	k = 0.0079				0.9959	0.0129	0.0010	0.0316
	T_2	k = 0.0059				0.9947	0.0237	0.0011	0.0328
	T_3	k = 0.0057				0.9959	0.0168	0.0007	0.0270
Henderson & Pabis	Control	a = 1.0316	k = 0.0085			0.9976	0.0036	0.0003	0.0161
	T_1	a = 1.0493	k = 0.0083			0.9944	0.0090	0.0007	0.0274
	T_2	a = 1.0544	k = 0.0062			0.9930	0.0177	0.0008	0.0291
	T_3	a = 1.0468	k = 0.0059			0.9949	0.0123	0.0006	0.0237
Wang & Sing	Control	b = -0.0059	$a = 8.73\times10^{-6}$			0.9852	0.0244	0.0017	0.0417
	T_1	b = -0.0059	$a = 9.17\times10^{-6}$			0.9948	0.0073	0.0006	0.0247
	T_2	b = -0.0041	$a = 4.17\times10^{-6}$			0.9887	0.0266	0.0013	0.0356
	T_3	b = -0.0039	$a = 3.88\times10^{-6}$			0.9858	0.0347	0.0016	0.0397
Logarithmic	Control	a = 1.0407	k = -0.0081	c = -0.0151		0.9979	0.0030	0.0002	0.0153
	T_1	a = 1.0959	k = -0.0070	c = -0.0667		0.9975	0.0034	0.0003	0.0176
	T_2	a = 1.0820	k = -0.0054	c = -0.0484		0.9958	0.0088	0.0004	0.0004
	T_3	a = 1.0649	k = -0.0054	c = -0.0335		0.9963	0.0077	0.0004	0.0191
Demir *et al*	Control	a = 1.0407	k = 0.0328	n = 0.2470	b = -0.0150	0.9979	0.0030	0.0003	0.0159
	T_1	a = 1.0959	k = 0.0234	n = 0.3018	b = -0.0666	0.9975	0.0034	0.0003	0.0185
	T_2	a = 1.0820	k = 0.0216	n = 0.2509	b = -0.0483	0.9958	0.0088	0.0005	0.0215
	T_3	a = 1.0649	k = 0.0244	n = 0.2206	b = -0.0334	0.9963	0.0077	0.0004	0.0196

T_1= 0.5 % KMS, T_2= 1 % KMS, T_3=1.5 % KMS

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Table 4: Correlation parameters and model constants for the selected thin layer drying models at 60 ℃

Model Name	Pre-treatment	Constants			R^2	SSE	MSE	RMSE
Newton	Control	k = 0.0090			0.9959	0.0081	0.0005	0.0233
	T_1	k = 0.0072			0.9937	0.0157	0.0010	0.0324
	T_2	k = 0.0093			0.9947	0.0104	0.0007	0.0264
	T_3	k = 0.0095			0.9941	0.0088	0.0006	0.0242
Henderson & Pabis	Control	a = 1.0287		k = 0.0092	0.9955	0.0068	0.0005	0.0221
	T_1	a = 1.0505		k = 0.0075	0.9929	0.0113	0.0008	0.0284
	T_2	a = 1.0284		k = 0.0096	0.9942	0.0092	0.0007	0.0256
	T_3	a = 1.0177		k = 0.0097	0.9940	0.0084	0.0006	0.0244
Wang & Sing	Control	b = -0.0062	$a = 9.44\times10^{-6}$		0.9839	0.0284	0.0020	0.0450
	T_1	b = -0.0054	$a = 7.71\times10^{-6}$		0.9955	0.0071	0.0005	0.0226
	T_2	b = -0.0063	$a = 9.77\times10^{-6}$		0.9830	0.0310	0.0022	0.0470
	T_3	b = -0.0064	$a = 9.96\times10^{-6}$		0.9763	0.0428	0.0031	0.0553
Logarithmic	Control	a = 1.0413	k = -0.0087	c = -0.0206	0.9961	0.0055	0.0004	0.0206
	T_1	a = 1.0739	k = -0.0069	c = -0.0357	0.9940	0.0090	0.0007	0.0262
	T_2	a = 1.0436	k = -0.0089	c = -0.0247	0.9950	0.0071	0.0005	0.0234
	T_3	a = 1.0234	k = -0.0094	c = -0.0096	0.9942	0.0080	0.0006	0.0248
Demir *et al*	Control	a = 1.0413	k = 0.0330	n = 0.2628 b = -0.0205	0.9961	0.0055	0.0005	0.0215
	T_1	a = 1.0739	k = 0.0165	n = 0.4171 b = -0.0357	0.9940	0.0090	0.0007	0.0273
	T_2	a = 1.0436	k = 0.0356	n = 0.2509 b = -0.0246	0.9950	0.0071	0.0006	0.0244
	T_3	a = 1.0234	k = 0.0620	n = 0.1514 b = -0.0095	0.9942	0.0080	0.0007	0.0259

T_1= 0.5 % KMS, T_2= 1 % KMS, T_3=1.5 % KMS

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Table 5: Correlation parameters and model constants for the selected thin layer drying models at 70 ℃

Model Name	Pre-treatment	Constants		R^2	SSE	MSE	RMSE
Newton	Control	k = 0.0084		0.9935	0.0085	0.0006	0.0246
	T_1	k = 0.0080		0.9919	0.0135	0.0010	0.0311
	T_2	k = 0.0089		0.9933	0.0171	0.0011	0.0327
	T_3	k = 0.0072		0.9894	0.0355	0.0020	0.0444
Henderson & Pabis	Control	a = 1.0104	k = 0.0085	0.9938	0.0083	0.0006	0.0253
	T_1	a = 1.0369	k = 0.0083	0.9917	0.0113	0.0009	0.0295
	T_2	a = 1.0507	k = 0.0093	0.9925	0.0131	0.0009	0.0295
	T_3	a = 1.0684	k = 0.0077	0.9872	0.0272	0.0016	0.0400
Wang & Sing	Control	b = -0.0063	$a = 10.3 \times 10^{-6}$	0.9827	0.0254	0.0020	0.0442
	T_1	b = -0.0060	$a = 9.46 \times 10^{-6}$	0.9913	0.0124	0.0010	0.0309
	T_2	b = -0.0060	$a = 8.74 \times 10^{-6}$	0.9798	0.0361	0.0024	0.0491
	T_3	b = -0.0051	$a = 6.33 \times 10^{-6}$	0.9907	0.0178	0.0010	0.0324
Logarithmic	Control	a = 0.9930	k = -0.0093 c = 0.0297	0.9951	0.0061	0.0005	0.0225
	T_1	a = 1.0455	k = -0.0080 c = -0.0133	0.9919	0.0110	0.0009	0.0303
	T_2	a = 1.0673	k = -0.0087 c = -0.0270	0.9935	0.0102	0.0007	0.0270
	T_3	a = 1.1020	k = -0.0067 c = -0.0533	0.9905	0.0175	0.0011	0.0331
Demir *et al*	Control	a = 0.9930 k = 0.0303	n = 0.3078 b = 0.0298	0.9951	0.0061	0.0006	0.0235
	T_1	a = 1.0455 k = 0.0251	n = 0.3192 b = -0.0133	0.9919	0.0110	0.0010	0.0316
	T_2	a = 1.0673 k = 0.0361	n = 0.2399 b = -0.0269	0.9935	0.0102	0.0008	0.0281
	T_3	a = 1.1020 k = 0.0278	n = 0.2398 b = -0.0533	0.9905	0.0175	0.0012	0.0341

T_1= 0.5 % KMS, T_2= 1 % KMS, T_3=1.5 % KMS

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Table 6: Variation of effective moisture diffusivity with temperature and pre-treatment

Temperature (°C)	Pre-treatment	Slope (S)	Effective Moisture Diffusivity (m^2s^{-1})	Coefficient of Determination (R^2)
50	Control	0.0085	8.61×10^{-8}a	0.9920
	T_1	0.0101	10.02×10^{-8}b	0.9902
	T_2	0.0079	8.00×10^{-8}c	0.9911
	T_3	0.0067	6.79×10^{-8}d	0.9872
60	Control	0.0092	9.32×10^{-8}ab	0.9699
	T_1	0.0078	7.90×10^{-8}ac	0.9703
	T_2	0.0098	9.93×10^{-8}ad	0.9539
	T_3	0.0089	9.02×10^{-8}ae	0.9494
70	Control	0.0068	6.89×10^{-8}ba	0.9415
	T_1	0.0078	7.90×10^{-8}bc	0.9654
	T_2	0.0098	9.93×10^{-8}bd	0.9721
	T_3	0.0092	9.32×10^{-8}be	0.9719

T_1= 0.5 % KMS, T_2= 1 % KMS, T_3=1.5 % KMS. Different lowercase letters indicate significant difference (p<0.05).

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Table 7: Effect of pre-treatment on activation energy and diffusion coefficient

Pre-treatment	**Activation Energy (kJmol^{-1})**	**Diffusion Coefficient (m^2s^{-1})**	**Coefficient of Determination (R^2)**
Control	10.1015	2.1303×10^{-9}	0.4893
T_1	12.0279	1.1177×10^{-9}	0.7640
T_2	10.0308	3.4643×10^{-6}	0.7649
T_3	14.7283	1.6971×10^{-5}	0.8404

T_1= 0.5 % KMS, T_2= 1 % KMS, T_3=1.5 % KMS