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Full Length Research Paper

Thin layer convective drying of mint leaves

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The drying kinetics of mint leaves (*Mentha spicata* L.) in terms of moisture content, moisture ratio, drying time and rate, and effective moisture diffusivity was investigated. A laboratory model tunnel dryer at a speed of 30 rpm was employed to study the drying behaviour at 45, 50, 55, 60 and 65°C. Mint leaves drying primarily occurred in falling rate period. The drying data were fitted to seven thin layer-drying models and the two-term model satisfactorily described the drying behaviour of mint leaves with highest r^2 values. Effective moisture diffusivity (D_{eff}) of mint leaves found to increase with the increase in drying air temperature and it ranged from 1.2325×10^{-10} to 2.6568×10^{-10} m^2/s. The results of the study are very useful for commercial scale drying of mint leaves to optimize drying process and to achieve superior quality dried product.

Key words: Drying, mint leaves, thin layer drying models, effective moisture diffusivity, tunnel dryer.

INTRODUCTION

Mint leaves (*Mentha spicata* L.) are a common name for members of the Labiatae (Laminaceae Family). It is a large family of annual or perennial herbs and widely grown all over the world to reap its special herbal characteristics. They are herbaceous rhizome plants and emit quadrangular green or purple stalks. Several species are shrubby or climbing forms, but small trees rarely. Mint leaves are very popular in Mediterranean regions and represent a dominant part of the vegetation. Mint leaves are known for refreshing, antiseptic, anti-asthmatic, stimulative, diaphoretic, stomachic, and antispasmodic features. Mint leaves are used in both fresh and dried forms in different cuisines. Various authors (Park et al., 2002; The Columbia electronic Encyclopedia, 2005; Thompson, 2003) have indicated the use of mint leaves in a variety of dishes such as vegetable curries, chutney, fruit salads, vegetable salads, salad dressings, soups, desserts, juices, sherbets etc. Mint is also very popular in India and mainly cultivated in southern parts of Himalayan range including Punjab, Himachal Pradesh, Haryana, Uttar Pradesh and Bihar.

Essential mint oil is extracted either from freshly harvested mint leaves or from semidried or dried leaves through distillation process for industrial applications. Drying is one of the oldest methods of food preservation and represents a very important aspect of food processing. Drying of food products is aimed at longer storage periods, lower packaging requirements and shipping weights (Okos et al., 1992; Kadam et al., 2005, 2006; Kadam and Samuel, 2006). To analyze the drying behaviour of a food product, it is quintessential to study the drying kinetics of the food. Thin layer drying is widely used for fruits and vegetables to prolong their shelf life.

Among the wide range of models, thin layer drying models have found widest application because of their ease of use. They do not require evaluation of many models parameters as is common in more complex representations. Thin layer drying equations describe drying phenomena in a unified manner regardless of controlling mechanism.

The equations are used to estimate drying time of several products and generalize drying curves (Karathanos and Belessiotis, 1999). Thin layer drying models for agricultural products correlates moisture content of the material at any given point of time (after

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product's exposure to a constant relative humidity and temperature condition) and drying parameters (Midilli et al., 2002; Togrul and Pehliavan, 2002). Dried product quality entirely depends on different unit operations involved in drying process. Drying process should be undertaken in closed equipment to improve the quality of the product (Ertekin and Yaldiz, 2004). Industrial dryers should be used to achieve consistent quality of the product. Industrial dryers are rapid and provide uniform and hygienic dried product (Doymaz and Pala, 2002).

A number of studies for drying of fruits and vegetables have been reported by various authors (Maskan et al., 2002; Togrul and Pehlivan, 2002; Erenturk et al., 2004; Doymaz et al., 2006; Akpinar, 2006; Kadam et al., 2008, 2009a, 2009b, 2010). Limited information is available on drying kinetics of mint leaves. The presented work ascertains effect of tunnel dryer conditions on mint leaves and evaluates different thin layer drying model.

Theoretical considerations

The moisture contents of mint leaves during thin-layer drying were expressed in terms of moisture ratios (MR) and calculated from the following equation (Midilli, 2001; Erenturk et al., 2004).

$$MR = (M - M_e) / (M_o - M_e) \quad (1)$$

Where, M is the mean mint moisture content; M_o is the initial value; and M_e is the equilibrium moisture content. M_e in comparison to M_o and M is very small, hence M_e can be neglected and moisture ratio can be presented in simplified form (Doymaz, 2004; Goyal et al., 2007).

$$MR = M / M_O \quad (2)$$

Seven thin layer-drying equations were tested (Table 1) to select the best model for describing the drying curve equation of mint leaves. Non-linear regression analysis was performed for the drying data by using STATISTICA. The Models were tested on the basis of coefficient of determination (r^2) (Ozdemir and Devres, 1999; Yaldiz et al., 2001; Erenturk et al., 2004) chi-square (χ^2), and mean bias error (MBE) and root mean square error (RMSE). r^2 value should be higher for quality fit, whereas χ^2, MBE and RMSE values should be lower (Togrul and Pehlivan 2002; Demir et al., 2004; Erenturk et al., 2004; Goyal et al., 2007). The above mentioned parameters can be calculated as follows:

$$\chi^2 = \frac{\sum_{i=1}^{N} (MR_{\exp.i} - MR_{pre.i})^2}{N - z} \quad (3)$$

$$MBE = \frac{1}{N} \sum_{i=1}^{N} (MR_{pre.i} - MR_{\exp.i}) \quad (4)$$

$$RMSE = \left[\frac{1}{N} \sum_{i=1}^{N} (MR_{pre.i} - MR_{\exp.i})^2 \right]^{1/2} \quad (5)$$

Moisture diffusivity

Fick's diffusion equation for particles with slab geometry was used for calculation of effective moisture diffusivity. The mint leaves were dried after washing, the samples were considered of slab geometry (Doymaz, 2006). The equation is expressed as (Crank, 1975):

$$MR = \frac{8}{\pi^2} \exp\left(\frac{-\pi^2 D_{eff} t}{4 L^2} \right) \quad (6)$$

Equation (6) can be rewritten as:

$$D_{eff} = \frac{\ln MR - \ln \frac{8}{\pi^2}}{\left(\frac{\pi^2 t}{4 L^2} \right)} \quad (7)$$

The slope (K_o) is calculated by plotting ln(MR) versus time according to Equation (6) to determine the effective diffusivity for different temperatures.

$$k_o = \left(\frac{\pi^2 D_{eff}}{4 L^2} \right) \quad (8)$$

METHODS

The experiments were conducted at Drying Technology Lab, CIPHET, Ludhiana to study the thin layer drying behaviour of mint leaves using tunnel dryer. Mint samples were dried at 45, 50, 55, 60 and 65°C in a tunnel dryer. Samples were replicated thrice in each case of drying. The weight loss data were noted during drying of mint at an interval of 30 min.

Sample preparation

Mint was procured from local market and cleaned by removing undesired stems and waste materials as shown in the process flow chart (Figure 1). The excess water was removed with the help of laboratory blotting paper. The damaged and black leaves were separated manually under careful observation before putting them in to dryer. The known weights of samples were taken and mint leaves were uniformly spread in thin layers in the drying trays. A sample size of 300 g was used for the study.

Table 1. Name of the models given by various researchers in the literatures.

S. no	Name of the model	Model equation
1	Newton	MR = Exp(-k*t)
2	Henderson and Pabis	MR = a * Exp(- k * t)
3	Logarithmic	MR = a * Exp(- k * t) + c
4	Two-term	MR = a * Exp(-k * t) + b * Exp(-n * t)
5	Two-term exponential	MR = a * Exp(-k * t) + (1-a) * Exp(-k *a* t)
6	Wang and singh	MR = 1 + (a * t) + (b * (t ** 2))
7	Diffusion approach	MR = a * Exp(-k * t) + (1-a) * Exp(-k *b* t)

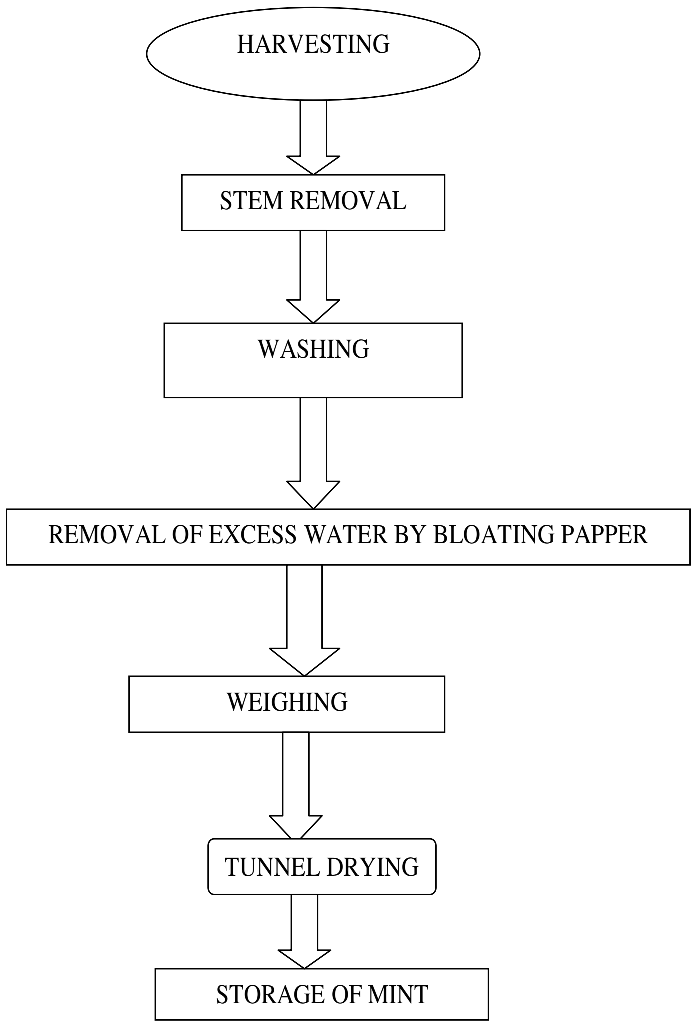

Figure 1. Flow chart of mint processing.

Tunnel dryer

A laboratory model cross flow tunnel dryer (NSW-600, Narang Scientific Works, New Delhi) was used for drying. The overall dimensions of the dryer were 3.06 m × 1.1 m × 2.15 m. The principle parts of the dryer were a tunnel, electrical heaters, fan and a temperature controller (30 to 110°C). The dryer was allowed to run for 30 min to reach the set drying air temperature conditions. The samples were dried in multiple passes in the dryer. Tunnel dryer was operated at a speed of 30 rpm.

Physical properties

Thickness, length and breadth of mint leaves were measured by using micrometer having a least count of 0.01 mm. The mentioned

Table 2. Physical dimensions of mint leaves (mm).

Sample	Thickness	Surface area (mm^2)
1	0.26	341
2	0.28	306
3	0.27	456
4	0.28	343
5	0.25	356
6	0.24	338
7	0.26	366
8	0.24	303
Mean	0.26	351.13
SEd	0.0068	35.45
$CD_{0.05}$	0.0166	86.74
$CD_{0.01}$	0.0251	131.42
CV%	3.68	14.28

Table 3. Name of the models given by various researchers in the literatures.

S. no	Name of the model	Model equation
1	Newton	MR = Exp(-k*t)
2	Henderson and Pabis	MR = a * Exp(- k * t)
3	Logarithmic	MR = a * Exp(- k * t) + c
4	Two-term	MR = a * Exp(-k * t) + b * Exp(-n * t)
5	Two-term exponential	MR = a * Exp(-k * t) + (1-a) * Exp(-k *a* t)
6	Wang and singh	MR = 1 + (a * t) + (b * (t ** 2))
7	Diffusion approach	MR = a * Exp(-k * t) + (1-a) * Exp(-k *b* t)

dimensions were used to calculate surface area of mint leaves. Colour of mint leaves was measured with the help of Hunter Lab MiniScan colorimeter (Model No-CO4-1005-631 Rev.E.). The experiments were repeated four times on individual samples to minimize the error.

Statistical analysis

The experimental data was analyzed as per the procedure of one way/ two way classified ANOVA using computer software package "AgRes" and modeling of convective thin layer drying of mint leaves was done by using "STATISTICA 11.0".

RESULTS AND DISCUSSION

Physical dimensions of mint leaves

The physical dimensions of mint leaves are shown in Table 2. The average thickness of leaves was 0.26 mm and average of surface area was 351.13 mm^2. The thickness of the leaves was more or less constant, but surface area varied from 303 to 456 mm^2 because of differing leaves width and length. Thickness and surface area of mint leaves were used to determine moisture diffusivity of mint leaves. The colour values of dry mint leaves showed that tunnel drying helped to retain colour of mint leaves. Table 3 presents the data on colour analysis and statistical analysis indicated that drying air temperatures (45 to 65°C) had no significant effect on colour of dried mint leaves at $CD_{0.05}$ level.

Drying characteristics of mint leaves

Moisture content of fresh mint leaves was 470.78% (db). It took 240 min at 65°C whereas it took 390 min at 45°C. It was observed that drying of mint leaves occurred primarily in falling rate period and no constant rate period was observed (Figure 2) at all drying temperatures. Moisture depletion per hour was higher at initial stages and then started to decrease with drying time. Drying in falling rate period indicated that initial mass transfer occurred by diffusion. Similar results have been reported for the drying studies (Yaldiz and Ertekin, 2001; Akpinar, 2006; Doymaz et al., 2006).

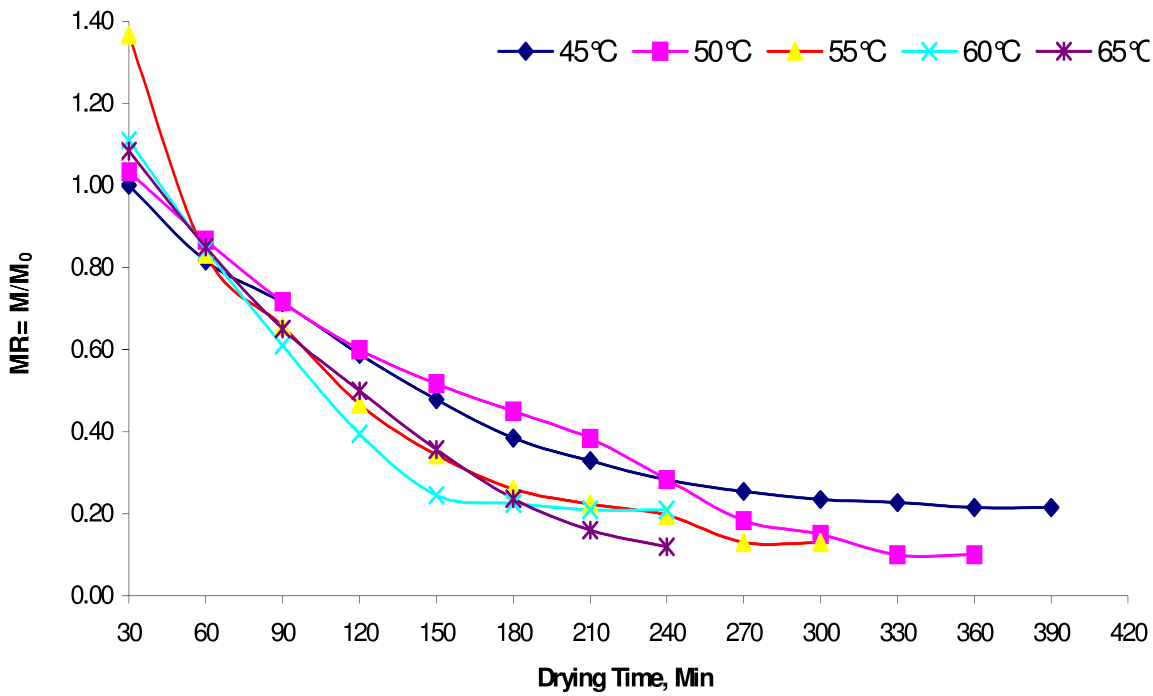

Figure 2. MR of tunnel dried mint leaves.

Table 4. Models statistical analyses results of thin layer tunnel drying of Mint leaves.

Temp, °C	Name of model	Equation	R^2	χ^2	MBE	RMSE
	1. Newton model	MR = Exp(-k*t)	0.8639	0.03280	0.03846	0.05206
	2. Henderson and Pebis	MR = a * Exp(- k * t)	0.8723	0.02358	-0.00907	0.04188
	3. Logarithmic	MR = a * Exp(- k * t) + c	0.9148	0.01127	-2.1×10^{-9}	0.03336
45	4. Two term	MR = a * Exp(-k * t) + b * Exp(-n * t)	0.9849	0.00174	0.00924	0.01004
	5. Two-term exponential	MR = a * Exp(-k * t) + (1-a) * Exp(-k *a* t)	0.9678	0.04593	0.05054	0.06300
	6. Wang and Singh	MR = 1 + (a * t) + (b * (t ** 2))	0.8325	0.03093	0.04527	0.04796
	7. Diffusion approach	MR = a * Exp(-k * t) + (1-a) * Exp(-k *b* t)	0.9681	0.00297	0.01307	0.01310
	1. Newton model	MR = Exp(-k*t)	0.9376	0.00708	0.01832	0.02326
	2. Henderson and Pebis	MR = a * Exp(- k * t)	0.9636	0.00458	-0.00407	0.01784
	3. Logarithmic	MR = a * Exp(- k * t) + c	0.9853	0.00194	-0.00375	0.01102
50	4. Two term	MR = a * Exp(-k * t) + b * Exp(-n * t)	0.9917	0.00137	-0.00099	0.00874
	5. Two-term exponential	MR = a * Exp(-k * t) + (1-a) * Exp(-k *a* t)	0.9376	0.00779	0.01832	0.02326
	6. Wang and Singh	MR = 1 + (a * t) + (b * (t ** 2))	0.9783	0.00263	0.00813	0.01352
	7. Diffusion approach	MR = a * Exp(-k * t) + (1-a) * Exp(-k *b* t)	0.9775	0.00296	0.00698	0.01361
	1. Newton model	MR = Exp(-k*t)	0.8026	0.03280	0.03846	0.05206
	2. Henderson and Pebis	MR = a * Exp(- k * t)	0.8723	0.02358	-0.00907	0.04188
	3. Logarithmic	MR = a * Exp(- k * t) + c	0.8799	0.02494	-6.1×10^{-9}	0.04061
55	4. Two term	MR = a * Exp(-k * t) + b * Exp(-n * t)	0.9838	0.00384	0.01323	0.01491
	5. Two-term exponential	MR = a * Exp(-k * t) + (1-a) * Exp(-k *a* t)	0.8026	0.03644	0.03845	0.05206
	6. Wang and Singh	MR = 1 + (a * t) + (b * (t ** 2))	0.8324	0.03093	0.04527	0.04796
	7. Diffusion approach	MR = a * Exp(-k * t) + (1-a) * Exp(-k *b* t)	0.9838	0.00336	0.01317	0.01491

Table 4. Continued.

60	1. Newton model	MR = Exp(-k*t)	0.8639	0.01802	0.02342	0.04219
	2. Henderson and Pebis	MR = a * Exp(- k * t)	0.8723	0.02059	0.02342	0.04219
	3. Logarithmic	MR = a * Exp(- k * t) + c	0.9149	0.01127	-2.1×10^{-9}	0.03336
	4. Two term	MR = a * Exp(-k * t) + b * Exp(-n * t)	0.9839	0.00212	0.00503	0.01449
	5. Two-term exponential	MR = a * Exp(-k * t) + (1-a) * Exp(-k *a* t)	0.8026	0.04593	0.05054	0.06301
	6. Wang and Singh	MR = 1 + (a * t) + (b * (t ** 2))	0.8324	0.03923	0.03792	0.05823
	7. Diffusion approach	MR = a * Exp(-k * t) + (1-a) * Exp(-k *b* t)	0.9838	0.00371	0.00291	0.01659
	1. Newton model	MR = Exp(-k*t)	0.8777	0.01623	0.02139	0.04004
	2. Henderson and Pebis	MR = a * Exp(- k * t)	0.9223	0.01179	-0.00994	0.03192
	3. Logarithmic	MR = a * Exp(- k * t) + c	0.9624	0.00499	-1.1×10^{-6}	0.02221
65	4. Two term	MR = a * Exp(-k * t) + b * Exp(-n * t)	0.9984	0.00034	-0.00082	0.00461
	5. Two-term exponential	MR = a * Exp(-k * t) + (1-a) * Exp(-k *a* t)	0.8778	0.01855	0.02139	0.04004
	6. Wang and Singh	MR = 1 + (a * t) + (b * (t ** 2))	0.9448	0.00838	0.01924	0.02691
	7. Diffusion approach	MR = a * Exp(-k * t) + (1-a) * Exp(-k *b* t)	0.9446	0.00980	0.01906	0.02695

Table 5. Moisture diffusivity and its linear equation for mint leaves at different drying temperatures.

Drying temperature, °C	Equation	k_o	D*eff*	R^2
45	y = -0.0045x - 0.0074	-0.0045	1.23256×10^{-10}	0.955
50	y = -0.0070x + 0.2788	-0.007	1.91731×10^{-10}	0.965
55	y = -0.0081x + 0.2425	-0.0081	2.2186×10^{-10}	0.966
60	y = -0.0082x + 0.1523	-0.0082	2.24599×10^{-10}	0.922
65	y = -0.0097x + 0.3105	-0.0097	2.65684×10^{-10}	0.964

Curve fitting of drying data

The moisture content data at the different drying air temperature were converted to moisture ratio and the same were fitted for the mentioned thin layer drying models (Table 1). The coefficient of correlation and results of statistical analyses are shown in Table 4. Although, r^2 values for the models were greater than 0.80 at all temperatures, the two-term model was superior with lowest values of χ^2, MBE and RMSE. Thus, the two term model with highest r^2 value of 0.998 adequately represented thin layer drying behaviour of mint leaves in tunnel dryer. Similar findings were reported for hot air drying of apricots (Togrul and Pehlivan, 2002; Doymaz, 2004), rosehip (Erenturk et al., 2004) and plum (Goyal et al., 2007).

Moisture diffusivity

Moisture diffusivity of mint leaves increased with the increase in drying air temperature. Moisture diffusivity (D_{eff}) varied from 1.2325×10^{-10} to 2.6568×10^{-10} m^2/s for temperature range from 45 to 65°C. These values are within the general range 10^{-9} to 10^{-11} m^2/s for drying of food materials (Maskan et al., 2002). Table 5 also shows the linear relationship between ln(MR) and time with r^2 values. The relationship between ln(MR) and time are shown in Figure 3 for drying of mint leaves at 45°C and similar trends were observed for other drying air temperatures.

Conclusion

Drying time varied from 240 to 390 min to dry a 300 g of mint leaves samples at temperatures from 45 to 65°C. The average thickness and moisture content of fresh mint leaves were 0.26 mm and 470.78% (db), respectively. Drying temperatures had no significant effect on the colour of dried mint leaves. Two-term model with highest r^2 value of 0.998 represented thin layer drying behaviour of mint leaves in tunnel dryer. Effective moisture diffusivity was observed to increase with the increase in drying air temperature and ranged from 1.2325×10^{-10} to 2.6568×10^{-10} m^2/s. The results of the study are useful to optimize drying process parameters for commercial scale production of dried mint leaves.

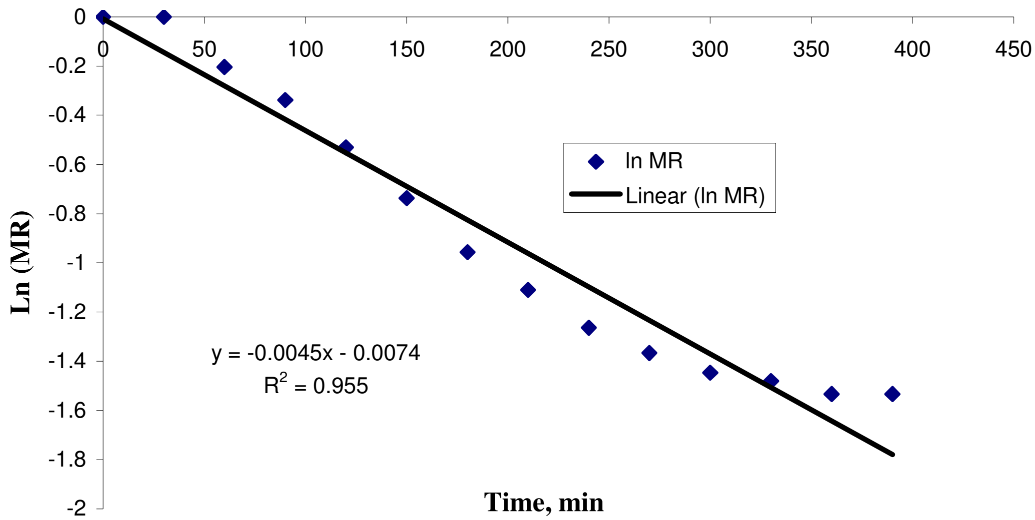

Figure 3. Ln (MR) at 45℃ during mint drying at tunnel dryer.

REFERENCES

Akpinar EK (2006). Mathematical modelling of thin layer drying process under open sun of some aromatic plants. J. Food Eng., 77: 864 – 870.

Crank J (1975). Mathematics of diffusion. UK: Clarendon Press, oxford.

Demir V, Gunhan T, Yagcioglu AK, Degirmencioglu A (2004). Mathematical modelling and the determination of some quality parameters of air-dried bay leaves. Biosyst. Eng., 88(3): 325 – 335.

Doymaz I, Pala M (2002). The effects of dipping pretreatments on air -drying rates of the seedless grapes. J. Food Eng., 52: 413-417.

Doymaz I (2004). Effect of pre-treatments using potassium metabisulphite and alkaline ethyl oleate on the drying kinetics of apricots. Biosyst. Eng., 89(3): 281–287.

Doymaz I (2006). Thin layer drying behaviour of mint leaves. J. Food Eng., 74: 370-375.

Doymaz I, Tugrul N, Pala M (2006). Drying characteristics of dill and parsley leaves. J. Food Eng., 77: 559-565.

Erenturk S, Gulaboglu MS, Gultekin S (2004). The thin layer drying characteristics of rosehip. Biosyst. Eng., 89 (2): 159 – 166.

Ertekin C, Yaldiz O (2004). Drying of eggplant and selection of a suitable thin layer drying models. J. Food Eng., 63: 349–359.

Goyal RK, Kingsly ARP, Manikanthan MR, Ilyas SM (2007). Mathematical modeling of thin layer drying kinetics of plum in a tunnel dryer. J. Food Eng., 79: 176–180.

Kadam D M, Lata, Samuel D V K, Pandey A K (2005). Influence of different treatments on dehydrated cauliflower quality. Int. J. Food Sci. Technol., 40: 849-856 doi:10.1111/j.1365-2621.2005.01007.x

Kadam D M, Samuel D V K (2006). Convective flat-plate solar heat collector for cauliflower drying. Biosyst. Eng., 93 (2): 189-198. doi:10.1016/j.biosystemseng. 2005.11.012

Kadam D M, Samuel D V K, Parsad R (2006). Optimisation of pre-treatments of solar dehydrated cauliflower. J. Food Eng., 77 (3): 659-664 doi:10.1016/j.jfoodeng.2005.07.027. Special Section: CHISA 2004 (pp. 379-471)

Kadam D M, Samuel D V K, Chandra P, Sikarwar H S (2008). Impact of processing treatments and packaging materials on some properties of stored dehydrated cauliflower. Int. J. Food Sci. Technol., 43: 1–14 doi:10.1111/j.1365-2621.2006.01372.x

Kadam D M, Nangare D D, Oberoi H S (2009a). Influence of pre-treatments on microbial load of stored dehydrated onion slices. Int. J. Food Sci. Technol., 44: 1902–1908 doi:10.1111/j.1365-2621.2009.01980.x

Kadam D M, Nangare D D, Singh R, Kumar S (2009b). Low Cost Greenhouse Technology for Drying Onion (Allium cepa L) Slices. J. Food Process Eng., doi: 10.1111/j.1745-4530.2008.00337.x

Kadam D M, Wilson R A, Kaur S (2010). Determination of biochemical properties of foam mat dried mango powder. Int. J. Food Sci. Technol., 45: 1626-1632 doi: 10.1111/j.1365-2621.2010.02308.x

Karathanos VT, Belessiotis VG (1999). Application of thin-layer equation to drying data of fresh and semi-dried fruits. J. Agric. Eng. Res., 74: 355-361.

Maskan A, Kaya S, Maskan M (2002). Hot air and sun drying of grape leather (pestil). J. Food Eng., 54: 81-88.

Midilli A (2001). Determination of pistachio drying behaviour and conditions in solar drying systems. Int. J. Energy Res., 25: 715-725.

Midilli A, Kucuk H, Yapar Z (2002). A new model for single layer drying. Drying Technol. 20(7): 1503-1513.

Okos MR, Narsimhan G, Singh RK, Weitnauer AC (1992). Food Dehydration. In D. R. Heldman DR, Lund DB (Eds). Handbook of Food Engineering, New York: Marcel Dekker.

Ozdemir M, Devres YO (1999). The thin layer-drying characteristic of hazelnuts during roasting. J. Food Eng., 42: 225-233.

Park KJ, Vohnikova Z, Brod FPR (2002). Evaluation of drying parameters and desorption isotherms of garden mint leaves (*Mentha crips* L.). J. Food Eng., 51: 193-199.

The Columbia Electronic Encyclopedia (2005). Columbia: Columbia University Press.

Thompson A K (2003). Fruits and vegetables (2^{nd} ed.) pp: 273. Oxford: Blackwell Publishing, UK.

Togrul IT, Pehlivan D (2002). Mathematical modelling of solar drying of apricots in thin layers. J. Food Eng., 55: 209-216.

Yaldiz O, Ertekin C (2001). Thin layer solar drying of some vegetables. Drying Technology 19: 583-596.

Yaldiz O, Ertekin C, Uzun HI (2001). Mathematical modelling of thin layer solar drying of sultana grapes. Energy–Int. J., 26: 457-465.