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DRYING OF MINT LEAVES UNDER CONTROLLED DRYING AIR TEMPERATURE AND RELATIVE HUMIDITY.

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ABSTRACT

A study was carried out to test and evaluate the drying behavior of mint leaves using a laboratory scale dryer with controlled air temperature and relative humidity.

The studied parameters included four different levels of drying air temperature (50, 55, 60 and 65°C) and four levels of air relative humidity (25, 30, 35 and 40%). All the experimental runs were conducted at constant air velocity of (0.23 m/sec). The drying behavior of mint leaves during the drying process were simulated using three different thin layer drying models (Lewis's 1921, Henderson and Pabis's 1961 and Page 1949 equations). Final quality of the dried mint leaves was also determined. The results show that, drying rate of mint leaves increased with the increase of drying air temperature while, it was decreased with the increase of relative humidity. All studied models could describe the drying behavior of mint leaves satisfactorily. However, Page's model considered the most proper for describing the drying behavior of mint leaves in terms of higher values of (R^2) and lower values of (χ^2), (MBE), (RMSE) and (SE). In general, the drying air temperature of 50°C and relative humidity of 25% achieved the best quality of the dried mint leaves in terms of total chlorophyll, total carotenoids and essential oil contents.

INTRODUCTION

The production of medicinal and aromatic plants considered as a good source of natural income as potential exporTable crops, among these plants Mint (*Mentha spicata* L.). Mint is one of the most important medicinal and aromatic plants throughout the world. It's a member of the Labiatae (Laminaceae Family) and very popular in Mediterranean regions, it's also represent a dominant part of the vegetation (Özbek and Dadali, 2007; Thompson, 2003).

The main component on mint is essential oil, its yield ranged from 0.62 - 1.70 % (g /100g of fresh matter) and from 0.1–1.8% (g/100 g of dry matter) (Özbek and Dadali, 2007; Hussain *et al*., 2010 and Kofidis *et al*., 2006).

Both fresh and dried mint leaves and their essential oils are widely used on account of its medicinal and aromatic components in pharmaceutical industries, food, cosmetic, confectionary, chewing gum and toothpaste. Mint leaves are used in herbal teas or as additives for different types of foods to offer aroma and flavor in commercial spice mixtures (Lawrence, 2006; Hadjlaoui *et al*., 2009). Due to the great importance of this seasonal plant and in order to preserve, make it available to consumers during the whole year and to avoid quality losses, it should be exposed to specific technological treatments, such as drying (Park *et al*., 2002).

Drying is the most common and fundamental method for preservation of medicinal and aromatic plants because it allows for quick conservation of the medicinal qualities of the plant material in an uncomplicated manner. It is a preparation process, carried out to meet the needs of the pharmaceutical industry, which does not have the suiTable conditions to use fresh plants on the scale required by industry (Lorenzi and Matos, 2002).

To analyze the drying behavior of mint leaves, it is quintessential to study the drying kinetics of the plant. Thin layer drying models have found to be the widest application in crop drying because of their simplicity in use. It can also correlates the changes in moisture content of the material at any given point of time with the drying parameters (Midilli *et al*., 2002; Togrul and Pehlivan, 2002).

The present study aims to provide a rational basis for the artificial drying of mint leaves, in which forced heated air under controlled temperature and relative humidity was used to remove the excess moisture content. The final quality of the dried mint leaves was also determined.

MATERIALS AND METHODS

Freshly harvested mint was obtained from the experimental station of Mansoura University at initial moisture content ranged between 77 and 87% wb.

To achieve the objective of the present study, a controlled drying air temperature and relative humidity laboratory scale dryer developed and installed at the Agricultural Engineering Department, Faculty of Agric. Mansoura University was used. The dryer can generate any desired condition for both drying air temperature and relative humidity.

The main components of the dryer included 1.3 kW centrifugal blower with straight impeller, humidity control system in which water was spread and circulated through a humidification tower in order to provide and maintain the drying air at the desired dew point temperature by means of a thermostat with an accuracy of ±0.1˚C. The air temperature was controlled using air heating unit with a temperature controller adjusted the drying air temperature very satisfactorily. The samples were accommodated in drying chamber consisted of galvanized steel cylinder (27 cm diameter and 70 cm long) and a drying tray placed inside the cylinder as shown in Fig. (1).

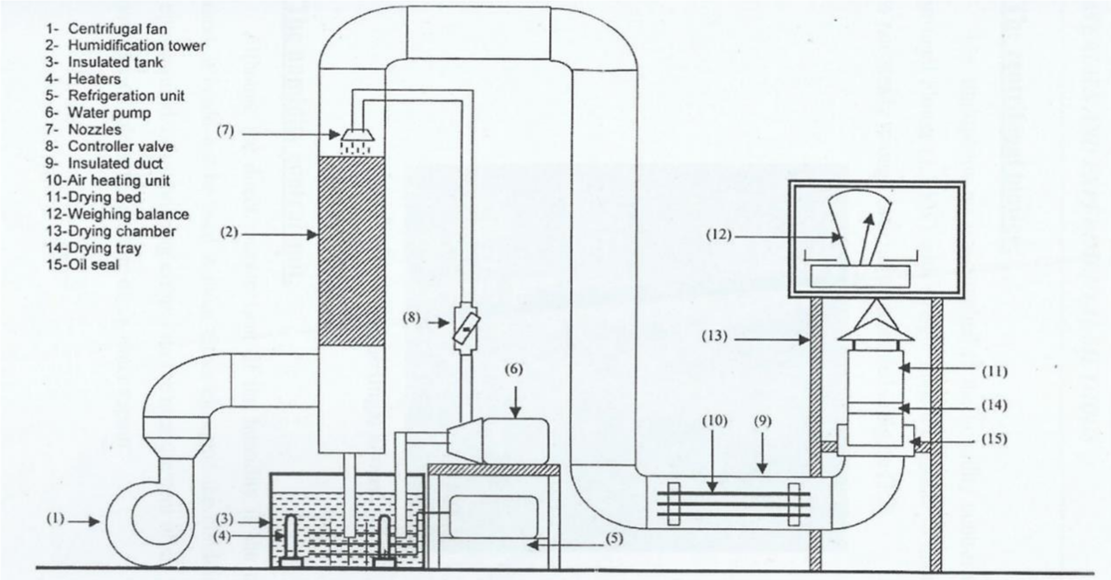

Fig. (1): Diagrammatic section of the laboratory scale dryer.

Experimental Measurements and Measuring Equipment.

1-Air temperature and relative humidity:

A temperature and relative humidity meter model (Trotec - 2000S) connected to an Iron-Constantine thermocouple type (T) was used to measure both parameters.

2-Air velocity:

A TRI-SENSE temperature/ humidity/ air velocity meter (model Trotec 2000S) was used for measuring air velocity over the samples surface with an accuracy of 0.01 m/s.

3-Mass measurement:

The mass of samples was recorded using a digital balance with accuracy of 0.01g.

4-Moisture content of mint leaves:

Initial and final moisture contents of mint leaves were determined using a German electric oven 1.2 kW (BINDER) at temperature of 105°C for 24 hours as described by the method of AOAC (1990).

Experimental procedure:

Mint was cleaned by removing undesired stems and impurities. Then the damaged and black leaves were separated manually under careful observation and the sound leaves were only used for the experimental work. Prior to each experimental run, air temperature, relative humidity and velocity had been stabilized, the mint leaves were uniformly spread in thin layers of 50 g for each sample in the perforated drying tray and charged into the dryer bed. At the same time three sub samples each of 5 g were taken from the fresh mint leaves and kept in an aluminum tin to determine the initial moisture content, the weight changes of the samples were recorded during the drying process every 5 minutes during the first two hours and every 10 minutes up to the end of each run, or in other words until the moisture content of mint leaves had approached the equilibrium condition with the drying air. At the end of each drying run the final weight of mint leaves were assessed and then the dried leaves were used to determine the final moisture content as explained before. In order to minimize the experimental errors of each run, it was replicated three times, and the average reading was considered.

Simulation of the Drying Data:

The obtained data of the laboratory experiments were employed to examine the applicability of the three studied thin layer drying models (Lewis's 1921, Henderson and Pabis's 1961 and Page 1949 equations) on describing and simulating the drying data.

The examined drying models could be presented as follows:

Lewis's model:

$$MR = \frac{M - M_f}{M_o - M_f} = exp(-k_L\, t) \ldots\ldots\ldots\ldots\ldots\ldots\ldots. (1)$$

Where:

MR: Moisture ratio, dimensionless.

M: Instantaneous moisture content during the drying process, % (d.b).

M_o: Initial moisture content of mint leaves samples, % (d.b).

M_f : Final moisture content of mint leaves samples, % (d.b).

k_L: Drying constant, min^{-1}.

t: Drying time, min.

The values of the drying constant (k_L) for the Lewis's model (1) could be obtained from the relationship between the natural logarithm Ln (MR) of the tested sample versus the drying time (t) as follows:

$$\mathbf{Ln\ MR = -\ k_L\ t}$$

The drying constant (k_L) represented by the slope of the equation.

Henderson and Pabis's model:

$$MR = A_H\,.exp(-k_H\, t) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

Where:

k_H: Drying constant, min^{-1}.

A_H: Drying constant, dimensionless.

The values of drying constants (k_H) and (A_H) for Henderson and Pabis's (equation 2) could be also obtained from the relationship between Ln (MR) versus the drying time (t) as follows:

$$Ln\ MR = Ln\ A_H - k_H\ t$$

The drying constant (k_H) represented by the curve slope while, the constant (A_H) represented by the y-intercept.

Page's model:

$$MR = exp(-k_p t^u) \qquad (3)$$

Where:

k_p: Drying constants, min^{-1}.

u: Drying constants, dimensionless.

The drying constants (k_P) and (u) of Page's model were determined after plotting the values of Ln (-Ln (MR)) versus the drying time (Ln (t)) as follows:

$$(Ln(-Ln(MR))) = Ln(k_P) + u\,Ln(t)$$

The slope of the drying curve represents the drying constant (k_P) while the constant (u) represents the y-intercept.

Statistical analysis:

Regression analyses were proceeded by using the Statistical routine. Correlation coefficient (r) was one of the primary criterions for selecting the most appropriate equation to define the thin layer drying curves of the dried samples. In addition to (r), the various statistical parameters such as; reduce chi-square (χ^2), mean bias error (MBE) and root mean square error (RMSE) were used to determine the quality of the fit. The best fit was decided for the highest value of (R^2) and minimum value of (χ^2), (MBE) and (RMSE) as stated by Togrul and Pehlivan (2002); Demir *et al*. (2004); Erenturk *et al*. (2004) and Goyal *et al*. (2007).

The following mathematical relationships were utilized to calculate the mentioned statistical parameters:

$$\chi^2 = \frac{\sum_{i=1}^{N}(MR_{obs.,i} - MR_{calc.,i})^2}{N-n} \qquad (4)$$

$$MBE = \frac{1}{N}\sum_{i=1}^{N}(MR_{calc.,i} - MR_{obs.,i}) \qquad (5)$$

$$RMSE = \left[\frac{1}{N}\sum_{i=1}^{N}(MR_{calc.,i} - MR_{obs.,i})^2\right]^{1/2} \qquad (6)$$

Where:

$MR_{obs.,i}$: observed moisture ratio.

$MR_{calc.,i}$: calculated moisture ratio.

N: number of observations.

n : number of constants.(Pangavhane *et al*., 1999).

Quality evaluation of the dried mint leaves:

The total chlorophyll (mg/g) and total carotenoids (mg/g) were determined according to the method of Mackinny (1941). While, the essential oil content was determined according to methods described by the Egyptian pharmacopeia (1984).

RESULTS AND DISCUSSION

Moisture content of mint leaves:

The changes in moisture content of mint leaves as related to drying time at different levels of drying air temperature and relative humidity are illustrated in Fig. (2). It clearly showed that, both drying air temperature and relative humidity had a great effect on the drying behavior of mint leaves. As the drying air temperature increased and the relative humidity decreased the drying rate of mint leaves increased.

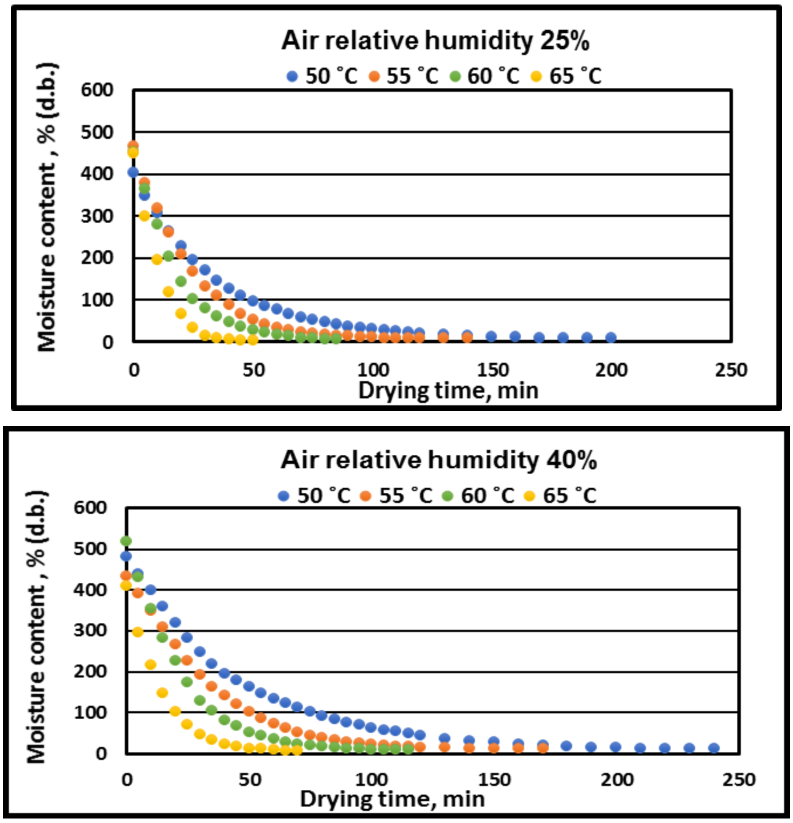

Fig. (2): Change in moisture content of mint leaves as related to drying time at different levels of drying air temperature and relative humidity of 25 and 40%.

Drying analysis of mint leaves using Lewis's model:

Fig. (3) illustrates the method of determining the drying constant (k_L) of Lewis's model and Table (1) presents the obtained data of the constant (k_L) at different levels of drying air temperature and relative humidity.

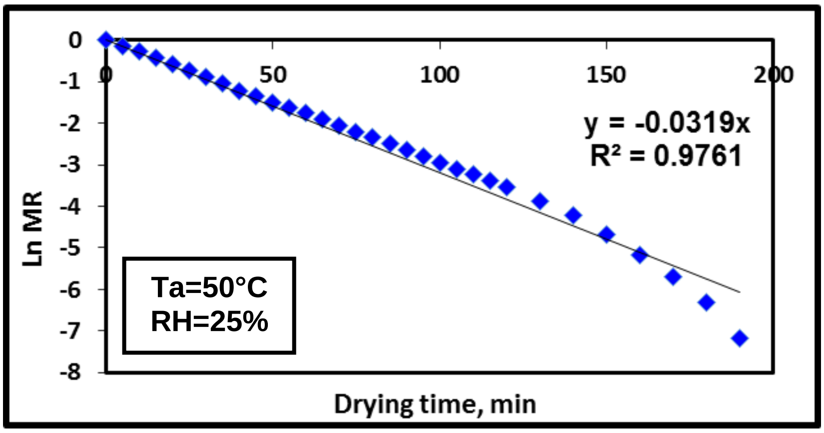

Fig. (3): Determination of the drying constant (k_L) of Lewis's model.

Table (1): Values of the drying constant (k_L) for Lewis's model.

Air temp., °C	Air relative humidity, % 25	30	35	40
50	0.0325	0.0300	0.0270	0.0260
55	0.0495	0.0440	0.0410	0.0380
60	0.0660	0.0620	0.0570	0.0530
65	0.1035	0.0970	0.0915	0.0860

As shown in Table (1), the drying constant (k_L) increased with the increase of drying air temperature, while it was decreased with the increase of drying air relative humidity.

A multiple regression analysis was proceeded to relate the drying air temperature (Ta) and relative humidity (RH) with the drying constant (k_L) at constant air velocity of 0.23 m/sec. The nature of dependence could be expressed by the following equation:

$k_L = 0.00427\ Ta - 0.0008\ RH - 0.1624$ ……………..…. (7)

(S.E. = 0.00633 $R^2 = 0.94762$ r = 0.97346)

Drying analysis of thin layer drying of mint leaves using Henderson and Pabis's model:

Fig. (4) illustrates the method of determining the drying constants (k_H), (A_H) of Henerson and Papis's model and Table (2) presented the obtained data.

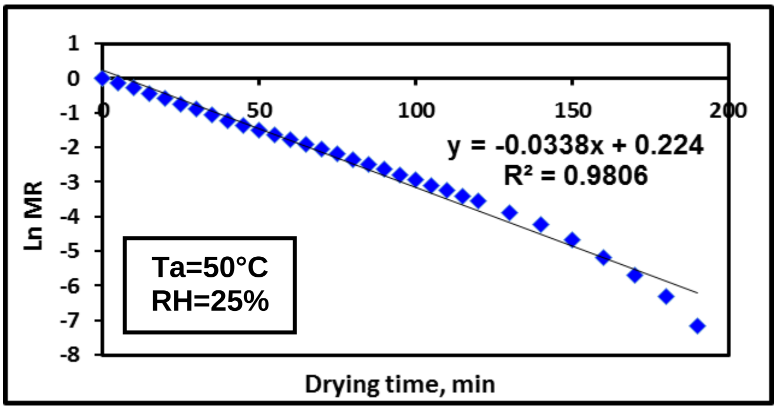

Fig. (4): Determination of the drying constants (k_H) and (A_H) of Henderson and Pabis's model.

Table (2): Values of the drying constants (k_H) and (A_H) for Henderson and Pabis's model.

Air temp., °C	Air relative humidity, % 25		30		35		40	
	k_H	A_H	k_H	A_H	k_H	A_H	k_H	A_H
50	0.0345	1.2580	0.0325	1.3236	0.0300	1.3947	0.0290	1.4737
55	0.0535	1.4102	0.0500	1.5208	0.0447	1.5289	0.0420	1.6071
60	0.0720	1.4915	0.0660	1.5522	0.0615	1.6630	0.0590	1.7441
65	0.1190	1.5769	0.1100	1.6383	0.1035	1.7487	0.0930	1.7752

As shown in Table (2), both drying constants (k_H) and (A_H) increased with the increase of drying air temperature, while the drying constant (k_H) decreased with the increase of drying air relative humidity and constant (A_H) increased with the increase of drying air relative humidity.

A multiple regression analysis was proceeded to relate the drying air temperature (Ta) and relative humidity (RH) with both drying constant (k_H) and (A_H). The nature of dependence could be expressed by the following equations:

k_H = 0.00483 Ta – 0.00093 RH – 0.18509 ……… (8)
(S.E. = 0.00829 R^2 = 0.93141 r = 0.96510)

A_H = 0.02126 Ta + 0.01446 RH – 0.14787 ……… (9)
(S.E. = 0.03069 R^2 = 0.96426 r = 0.98197)

Drying analysis of thin layer drying of mint leaves using Page's model:

Fig. (5) illustrates the method of determining the drying constants (k_P), (u) of Page's model and Table (3) presented the obtained data.

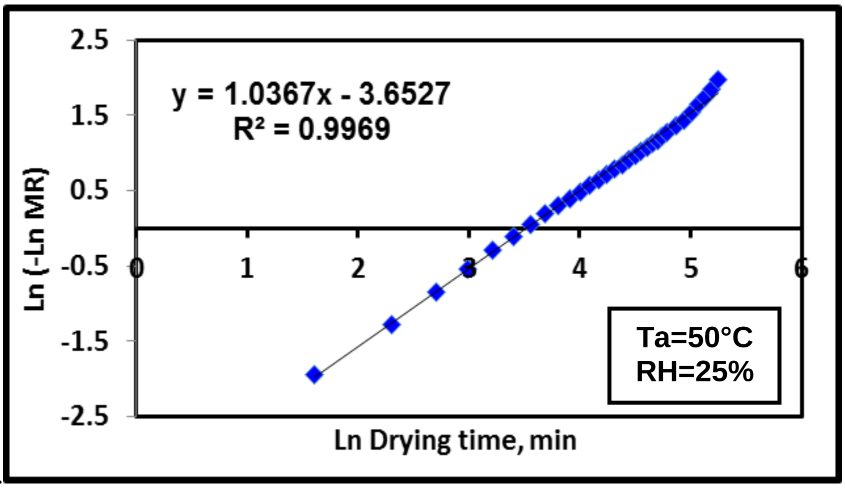

Fig. (5): Determination of the drying constants (k_P,u) of Page's model.

Table (3): Values of the drying constants (k_P) and (u) for Page's model.

Air temp., °C	Air relative humidity, %							
	25		30		35		40	
	k_p	u	k_p	u	k_p	u	k_p	u
50	0.0196	1.0729	0.0185	1.0949	0.0156	1.0978	0.0148	1.1290
55	0.0212	1.1250	0.0190	1.1314	0.0177	1.1754	0.0170	1.1989
60	0.0273	1.1780	0.0226	1.1990	0.0209	1.2211	0.0205	1.2397
65	0.0376	1.2599	0.0333	1.2686	0.0317	1.2783	0.0304	1.2867

As shown in Table (3), both drying constants (k_P) and (u) increased with the increase of drying air temperature, while the drying constant (k_P) decreased with the increase of drying air relative humidity and drying constants (u) increased with the increase of air relative humidity.

A multiple regression analysis was proceeded to relate the drying air temperature (Ta) and relative humidity (RH) with both drying constant (k_P) and (u). The obtained equations could be presented as follows:

k_P = 0.00105 (Ta) – 0.00038 (RH) + 0.02498 …… (10)
(S.E. = 0.00267 R^2 = 0.871 r = 0.93327)

u = 0.01152 Ta + 0.00367 RH + 0.40321 ……… (11)
(S.E. = 0.00996 R^2 = 0.98265 r = 0.991287)

The applicability of the studied models in simulating the drying data:

Figs. (6) illustrates the observed and calculated values of moisture content of mint leaves at 50^{0}C drying air temperature and of 25% air relative humidity. The results show that, all studied models described the drying behavior of mint leaves satisfactorily as indicated by the high values of coefficient of determination (R^2) and low values of standard error (SE).

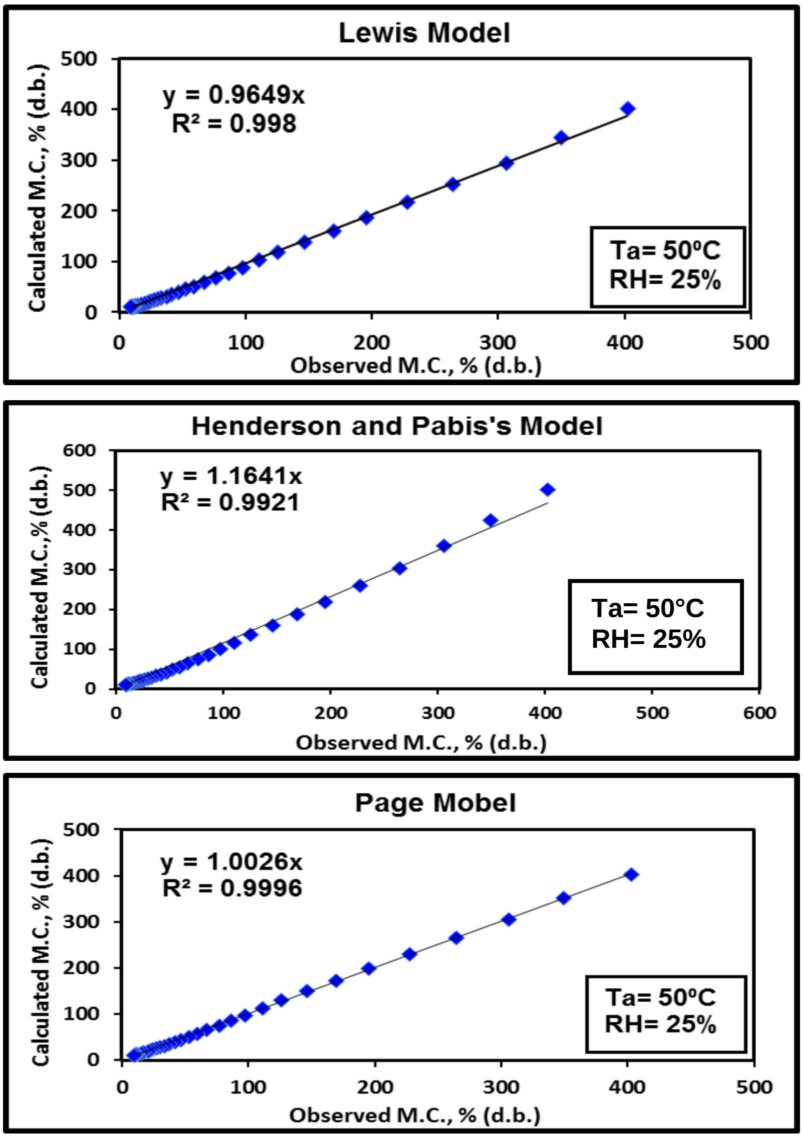

Fig. (6): The observed and calculated moisture content values of mint leaves using all the studied models.

Comparative evaluation of the studied drying models:

In general, all the studied models could describe the drying behavior of mint leaves as indicated from the high values of (R^2). However, to assess the most proper model for describing the drying behavior of mint leaves and in addition to the high values of (R^2), various statistical parameters such as (r), (χ^2), (MBE) and (RMSE) were calculated. The results show that, Page's model recorded the highest value of (r) and the lowest values (χ^2), (MBE), (RMSE). This means that, Page's model is the most proper model for describing the drying behavior of mint leaves under the studied ranges of drying air temperature and relative humidity.

Quality of mint leaves:

Mint leaves dried at air temperature of 65ºC at all studied levels of relative humidity and also the samples dried at air temperature of 60ºC and air relative humidity of (25, 30%) have been excluded form quality evaluation tests of the dried mint leaves due to over drying of mint leaves samples or in other words, the final moisture contents of leaves were below the safe storage moisture content of (8%) as mentioned by Farias (2003).

Total Chlorophyll, Carotenoids and Essential oil contents:

Table (4) illustrates the changes in chlorophyll *a*, chlorophyll *b*, total (*a* + *b*) chlorophyll, total carotenoids (mg/g) and essential oil (ml/100g) of mint leaves at different levels of drying air temperature and relative humidity. As shown in the Table, the optimum conditions keeping the final quality of the dried mint leaves, are drying air temperature of 50 ^{o}C and relative humidity of 25% which recorded the highest contents of chlorophyll *a* (0.672 mg/g), chlorophyll *b* (0.462 mg/g), total (*a* + *b*) chlorophyll (1.134 mg/g), total carotenoids (0.0374 mg/g) and essential oil (2.50 ml/ 100g).

Table (4): Total chlorophyll and carotenoids content in mint leaves as influenced by the drying parameters

Treatments	Cholorophyll (mg/g)			Carotenoids (mg/g)	Essential oil (ml/ 100g)
	a	*b*	*a+b*		
Control	0.706	0.493	1.199	0.0395	3.23
50˚C / 25%	0.672	0.462	1.134	0.0374	2.50
50˚C / 30%	0.653	0.445	1.098	0.0362	2.25
50˚C / 35%	0.637	0.43	1.067	0.0347	2.13
50˚C / 40%	0.623	0.418	1.041	0.0333	1.88
55˚C / 25%	0.655	0.456	1.111	0.0367	2.38
55˚C / 30%	0.64	0.443	1.083	0.0349	2.00
55˚C / 35%	0.626	0.428	1.054	0.0337	1.75
55˚C / 40%	0.615	0.415	1.03	0.0328	1.63
60˚C / 35%	0.617	0.418	1.035	0.033	1.38
60˚C / 40%	0.605	0.406	1.011	0.0321	1.13

CONCLUSIONS

1- The moisture ratio of mint leaves increased with the increase of drying air temperature. While, it was decreased with the increase of relative humidity.
2- All studied models (Lewis's, Henderson and Pabis's and Page’s model) could describe the drying behavior of mint leaves satisfactory however Page's model could be considered the most proper model for describing the drying behavior of mint leaves.
3- The optimum conditions keeping the final quality of the dried mint leaves are 50°C drying air temperature and 25% (RH).

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تجفيف أوراق النعناع تحت ظروف التحكم فى درجة الحرارة والرطوبة النسبية لهواء التجفيف.

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تم إجراء البحث لدراسة تأثير كل من درجة حرارة هواء التجفيف ورطوبتة النسبية على خصائص تجفيف أوراق النعناع واختبار ومقارنة ثلاث نماذج رياضية مختلفة لوصف عملية التجفيف فى طبقات رقيقة وتحديد النموذج الأمثل لوصف منحنيات التجفيف وإختبارامكانية تطبيقه للتنبؤ بالتغير فى المحتوى الرطوبى لأوراق النعناع أثناء عملية التجفيف ثم إجراء إختبارات الجودة لأوراق النعناع المجففة لتحديد التغيرات التى طرأت عليها أثناء عملية التجفيف.

ولتحقيق أهداف الدراسة تم إستخدام مجفف معملى يمكنه التحكم فى درجة حرارة هواء التجفيف ورطوبتة النسبية وتم إجراء التجارب المعملية لأوراق النعناع عند أربعة مستويات مختلفة من درجة حرارة هواء التجفيف (50, 55, 60, 65 °م) وأربعة مستويات مختلفة لرطوبة الهواء النسبية (25, 30, 35, 40 %) كما تم إجراء جميع التجارب المعملية عند سرعة هواء ثابتة (0.23 م/ث) .

وكانت أهم النتائج المتحصل عليها كالأتى:

1. معدل التناقص فى المحتوى الرطوبى لأوراق النعناع أثناء عملية التجفيف إزداد بزيادة درجة الحرارة بينما إنخفض بإنخفاض الرطوبة النسبية للهواء.
2. تمكنت جميع النماذج الرياضية المختبرة من وصف سلوك التجفيف لأوراق النعناع بصورة مرضية. ووجد أن معادلة Page هى النموذج الأمثل للتنبؤ بسلوك التجفيف مقارنة بالنماذج الأخرى حيث تمكنت من وصف منحنيات التجفيف والتنبؤ بالمحتوى الرطوبى بصورة أكثر دقة.
3. المعاملات المثلى التى حافظت على جودة أوراق النعناع المجففة هى درجة حرارة هواء التجفيف 50 °م و الرطوبة النسبية لهواء التجفيف 25%. حيث سجلت تلك المعاملات أعلى محتوى من الكلورفيل a (0.672 مجم/ جم) و كلورفيل b (0.462 مجم/ جم) والمحتوى الكلى لكلورفيل (a+b) (1.199 مجم/جم) والمحتوى الكلى لصبغة الكاروتين (0.0395مجم/ جم) وأعلى محتوى من الزيت العطرى (2.50 مل /100 جم).