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Influence of Drying Techniques on Drying Characteristics and Quality of Mint Leaves

تأثير تقنيات التجفيف المختلفة على خواص التجفيف والجودة لأوراق النعناع

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قسم هندسة النظم الزراعية، كلية العلوم الزراعية والأغذية، جامعة الملك فيصل، الأحساء، المملكة العربية السعودية

KEYWORDS
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Drying modelling, mint leaves, microwave, oven drying, solar drying

التجفيف الشمسي، اوراق النعناع، سلوك التجفيف، الميكرويف، الزيوت العطرية

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ABSTRACT

The method of conservation by drying is an important one, especially when used with medicinal and aromatic plants such as peppermint. There are many changes to colour and active substances, which affect the quality of the product. Three methods were used for drying mint leaves: oven drying (40, 50, 60 and 70 °C), microwave drying (180, 360, 540, 720 and 900 W) and solar drying with three levels of loading (0.5, 1.25 and 5 kg/m2). The drying characteristics and quality aspects of the dried mint leaves were studied. The shortest drying time to achieve the equilibrium moisture content (0.35 g, 0.38 g w/g d. m.) was five minutes by microwave drying at 900 and 720 W, with a loading level of 0.5 kg/m2, while the longest time taken to achieve equilibrium moisture content (0.72 g w/g d. m.) was 20 hours at 40 °C. Meanwhile, the solar drying method took eight hours to achieve the final moisture content (0.68 g w/g d. m.) at both 1.25 and 0.5 kg/m2 loading levels. The results showed that drying the mint leaves at a temperature of 50 °C, with a loading level of 1.25 kg/m2, was the best way to obtain the largest amount of essential oil. The Midili-Kucuk model adequately described oven and solar drying behaviours, and the logarithmic model adequately described microwave drying behaviour. In conclusion, solar drying (with its low cost) and oven drying (at 50 °C and loading level of 1.25 kg/m2) could both be effective methods of drying mint leaves, since they retain much of the essential oil. However, based on the results of this study, microwave drying is not an advisable method of obtaining aromatic oils from medicinal and aromatic plants.

الملخص

تستخدم النباتات الطبية والعطرية على نطاق واسع لإنتاج بعض الأدوية والمستحضرات الطبية والمكملات الغذائية . ويعتبر نبات النعناع من النباتات الطبية والعطرية الهامة التي لها اهمية كبيرة في كثير من الصناعات الدوائية والغذائية. وتستخدم النباتات الطبية والعطرية على صورة طازجة او محفوظة وتعتبر طريقة الحفظ بالتجفيف احد أهم الطرق التي تستخدم مع النباتات الطبية والعطرية والتي يحدث فيها العديد من التغيرات في اللون والمواد الفعالة مما يؤثر على جودة المنتج وعليه كان الهدف الرئيسي من هذا البحث هو الوصول الى انتاج نباتات مجففه ذات خصائص الجودة المطلوبة لأوراق النعناع . استخدمت ثلاث طرق للتجفيف وهي ا لتجفيف بالفرن الكهربائي عند درجات حرارة مختلفة وهي 40)، 50، 60، و (70 درجة مئوية ، والتجفيف بالميكروويف عند خمس مستويات من الطاقة وهي) 180، 360، 720 ,540و (900 وات والتجفيف الشمسي باستخدام المجفف الشمسي المختلط لأوراق النعناع بثلاثة مستويات تحميل للنعناع وهي (5، 1.25 ، 0.5 كجم/ م2).اوضحت النتائج ان التجفيف بالميكرويف في درجات حرارة عالية لا ينصح به في تجفيف النعناع بهدف الحصول على الزيوت العطرية حيث تؤدي الحرارة العالية الى فقد الزيوت ولكنه كان اسرع الطرق في التجفيف وحافظ على اكبر قدر من الكلوروفيل في النعناع. كان التجفيف الشمسي أكثر الطرق ملائمة لتجفيف النعناع حيث حافظ على كمية الزيت عند مستويات التحميل المختلفة بالإضافة لانخفاض تكاليفه. بالنسبة للتجفيف بالفرن الكهربائي كانت افضل المعاملات هي 50 درجة مئوية مع معدل تحميل 1.25 كجم/م2 حيث اعطت اكبر كمية من الزيت. عليه وبناءً على نتيجة هذه الدراسة، لا يُنصح بالتجفيف باستخدام الميكروويف للحصول على الزيوت العطرية للنباتات الطبية والعطرية. الموديل الرياضي–Midilli Kucuk ((MR = a exp (-k.tn) +b.t)يمكن استخدامه لوصف سلوك التجفيف الشمسي للعينات النعناع حيث أعطى أفضل النتائج عند التحميل 0.5 كجم/ م2.

1. Introduction

Mint (Mentha piperita) is one of the most important and common flavours in the world. Fresh or preserved forms of the Mentha species are used as condiments, and essential oils are also produced from them (Akgul, 1993; Doymaz, 2006). Peppermint is considered to be an important medicinal and aromatic plant which is of great importance in many pharmaceutical and food industries. The plants are used in fresh or preserved forms. Peppermint and its oil have been used in the dyeing, fragrance, cosmetic, beverage, confectionary, chewing gum and tobacco industries (Golestan et al., 2016). The basic essence of drying is to decrease the moisture content of the dried product to a level that prevents deterioration within a certain period of time (Ekechukwu, 1999). The drying method also has a significant effect on the proportion of the various components (Omidbaigiet et al., 2004). Sun drying of herbs enables production of a dried product with a rich colour and a translucent appearance, but has many disadvantages such as slowness of the process, environmental contamination, dependency on weather and labour requirements (Maskan, 2001). Salarikia et al. (2017) investigated the effects of hot air, infrared and combined hot air infrared drying methods on the drying time, energy consumption, colour, rehydration and oil content of peppermint leaves. However, the major drawbacks of conventional hot air drying are low energy efficiency and lengthy drying time during the last stage of drying (Soysal et al., 2006). Radünz (2004) and Therdthai and Zhou (2009) determined the characteristics of microwave assisted vacuum drying of mint leaves in comparison with conventional hot air drying. The effect on the colour and structure of the dried leaves required 13, 12 and 10 minutes, respectively, to reduce the moisture content to less than 0.1 kg water/kg dry matter. The main objective of this experiment was to investigate the effects of different drying methods (oven drying, solar drying and microwave drying), as well as different loading levels, on the drying characteristics and quality of mint leaves. The chemical compounds group was significantly decreased ($p < 0.01$) by microwave drying at power levels of 200 and 400 W (Beigia, 2018).

2. Materials and Methods

2.1. Materials:

2.1.1. Plant material

Fresh peppermint leaves (*Mentha piperita*.) were bought from the local market in Al-Ahsa, Saudi Arabia.

2.1.2. Microwave oven dryer

The microwave oven used was a KOR-9G2B with a maximum output of 900 W and 2450 MHz.The outside dimensions were 465*280*282 mm, and the cavity dimensions were (W*H*D) 314*235*346 mm, with a cavity volume of 26 L. A glass plate with a 30cm diameter was used to put the mint leaves on.

2.1.3. Oven dryer

The oven dryer used was a Rumo-10878 (German-made). The outside dimensions of the oven dryer were (W*H*D) 80*70*60 cm, and the cavity dimensions were (W*H*D) 50*60*50 cm.

2.1.4. Solar drying system

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The mixed solar dryer and storage unit were designed and manufactured at the Agricultural Systems Engineering Workshop, King Faisal University, Saudi Arabia. The drying system consisted of three main sections: the drying chamber (direct solar dryer), solar collector and solar storage unit as schematically depicted in Fig. 1. The dryer was mounted facing south, with a transparent cover tilted at an angle of 25º.56', which has been found to be the optimum tilt angle for the specific location and time of the year (Abdellatif, 1985). An extractor fan of 0.2 m external diameter (Sony, 20 wuc) and power of 220-240 V (50Hz) was situated at the top of the chimney. The air flow rate during the experiments was set at 0.075 m^3. Air heated by the solar collector was delivered to the drying chamber through a flexible insulated tube (15 cm diameter). The solar collector was orientated to face south at the optimum tilt angle. The dimensions of the storage unit were as follows: 1.5 m long, 0.70 m wide and 0.2 m deep. The walls and bottom of the dryer were constructed of plywood (10 mm thickness), and the space between the glass cover and storage material was 2.5 cm. The interior and exterior surfaces of the system were painted with a particular paint, according to Ghanem (2003).

2.2. Methods:

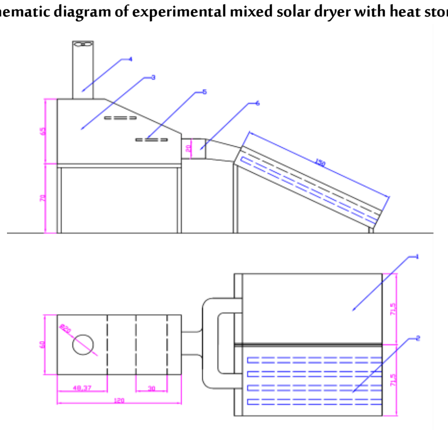
2.2.1. Experimental procedure

The fresh mint leaves were washed in water, and any excess water on the surface of the leaves was drained. The moisture content of the fresh mint leaves was measured using an Electric Moisture Balance (RADWAGE, www.radwag.com) made in Poland. The sample was divided into three parts, each of them dried using different methods as follows:

2.2.2. Solar drying

The peppermint leaves were distributed between two steel trays of sizes 0.1 * 0.1, 0.2*0.2 and 0.3*0.3 m, as samples to be weighted with three levels of loading: 5, 1.25 and 0.5 kg/m^2. These were then placed on the solar dryer trays. The remaining free space on the solar dryer trays was used for more mint with the same loading rates.

Fig. 1. Schematic diagram of experimental mixed solar dryer with heat storage unit



1-Solar collector	3-Drying chamber	5-Trays
2-Heat storage unit	4-Chimney	6-Duct

2.2.3. Microwave drying

The peppermint leaves were distributed uniformly with three levels of loading: 0.5, 1.25 and 5 kg/m^2. They were placed on to the glass microwave oven plate (diameter 30 cm), and the microwave was operated at different powers (180, 360, 540, 720 and 900 W). The microwave power cycle was 9s on/9s off.

2.2.4. Oven drying

The peppermint leaves were distributed between three steel trays with sizes of 0.1 * 0.1, 0.2*0.2 and 0.3*0.3 m, as samples to be weighted with three levels of loading: 5, 1.25 and 0.5 kg/m^2. They were then placed onto the trays of the oven dryer. The remaining free space on the oven dryer trays was used for more mint with the same loading rates.

2.2.5. Taking data

Data were obtained using three samples of peppermint, which were weighted and positioned at the centre and the two ends of each tray. The mass of the sample was measured every hour for the oven and solar drying methods (Gunhan et al, 2005; Maskan et al, 2002), and every minute for the microwave oven drying method (Fathima et al, 2001; Soysal et al, 2006).

3. Measurements:

3.1. Moisture Content:

The primary and final moisture content of the product was measured using an Electric Moisture Balance (RADWAGE, www.radwag.com), made in Poland. The moisture content was calculated during drying based on weight loss of samples and dry weight. The moisture content was calculated on a dry basis at any time, depending on weight loss, using the following equation:

$$M.C.(t)\ (db) = m_w / Dom \quad (1)$$

Where:

m_w = mass of the moisture in the sample at (t) g

D_m = mass of dry matter g

3.2. Drying Efficiency:

3.2.1. Solar Dryer efficiency:

$$\eta_{Ds.} = \frac{Wr*Lv}{I*A} * 100\ (\%) \quad (2)$$

Where: -

W_r= water removal, (kg/s).

L_v= latent heat of vaporisation, 2256.7*10^3 (J/kg).

I = solar intensity on horizontal surface (W/m^2)

A = surface area of drying chamber (m^2)

T = desired time period (s)

3.2.2. Oven dryer efficiency

$$\eta_{Do.} = Wr * \frac{LHV}{P} * 100 \quad (3)$$

Where :

Wr = water removal (kg/s)

LHV = Latent heat of vaporisation 2256.7*103 (J/Kg)

P = Power consumed (W)

P = V * I * COS φ , 1.159 KW. (4)

Where :-

V = Electrical voltage, 230V

I = The intensity of electric current, 6.3 by clamp meter COS φ = 0.8

- Microwave dryer efficiency:

$$\eta = Wr * \frac{LHV}{P} * 100 \quad (5)$$

Where :

Wr = water removal

(kg/s)

LHV = Latent heat of vaporisation 2256.7*103 (J/Kg)

P = Power consumed, 1350 (W)

3.3. Temperature:

The temperature of the air (°C) was continuously recorded at the required points with a thermocouple sensor (± 0.21 °C), using HOBO Data Loggers (Onset Computer Corporation®) with its relevant software (HOBOware™) at regular time intervals for all drying experiments.

3.4. Essential Oil Determination:

Fifty grams of the fresh and dried mint was placed in the distillation apparatus, then boiled for three hours (Board, 2003). The yielded oil was collected as the amount of oil per 100 g of dry weight.

3.5. Chlorophylls Determination:

Total chlorophylls were calculated using the following equations:

Chlorophyll A = (9.78×E 644)-(0.99×E 644), mg/litre (6)

Chlorophyll B = (21.426×E 644)-(4.65×E 662), mg/litre (7)

El-Yateem (1995)

where :

E = sample optical density at the indicated wave length.

3.6. Modelling the Drying Characteristics:

The drying curves of the different methods were fitted with eleven different moisture ratio equations, given by several researchers and cited by Idlimam et al. (2007), as listed in Table 1. The regression analysis was performed using statistical software (Data fit 9.0). The goodness fit between the predicted and experimental values for the tested mathematical models was evaluated from the coefficient of determination R^2 and the reduced chi-square χ^2. The higher the R^2 value, and the lower the χ^2 value, the better the goodness of fit will be (Ertekin and Yaldiz, 2004).

Table 1. Mathematical models applied to the drying curves (Idlimam et al., 2007).

Model number	Model name	Model expression
1	Newton	$MR = \exp(-k.t) = e^{-k.t}$
2	Page	$MR = \exp(-k.t^n) = e^{-k.tn}$
3	Henderson and Pabis	$MR = a.\exp(-k.t) = a.e^{-k.t}$
4	Logarithmic	$MR = a.\exp(-k.t)+c = a.e^{-k.t+c}$
5	Two term	$MR = a.\exp(-k_0.t) + b\exp(-k_1 t) = a.e^{-k0.t} + b\, e^{-k1\,t}$
6	Two term exponential	$MR = a.\exp(-k.t) + (1-a)\exp(-k.a.t) = a.e^{-k.t} + (1-a)\, e^{-k.a.t}$
7	Wang and Singh	$MR = 1+ a.t+bt^2 = 1+ a.t+bt^2$
8	Approximation of diffusion	$MR = a\exp(-k.t) + (1-a)\exp(-k.b.t) = a\, e^{-k.t} + (1-a)\, e^{-k.b.t}$
9	Modified Henderson and Pabis	$MR = a\exp(-k.t)+b.\exp(-g.t)+c.\exp(-h.t) = a\, e^{-k.t}+b.e^{-g.t}+c.e^{-h.t}$
10	Verma et al.	$MR = a\exp(-k.t) + (1-a)\exp(-g.t) = a\, e^{-k.t} + (1-a)\, e^{-g.t}$
11	Midilli-Kucuk	$MR = a\exp(-k.t^n) +b.t = a\, e^{-k.tn} +b.t$

Where

MR : moisture ratio

T : time, h

A,b,c,g,h,k,n : constant

4. Results and Discussion

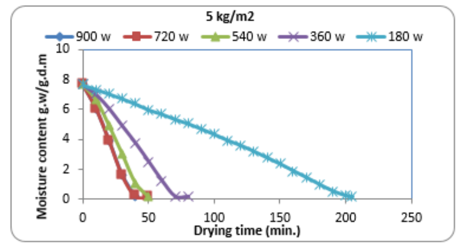
4.1. Influence of Different Drying Systems on Moisture Content:

4.1.1. Microwave drying

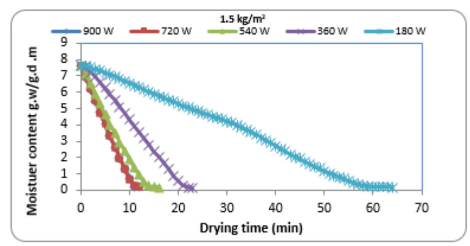
Fig. 2 (a, b and c) describes the microwave drying curves of moisture content versus drying time, the microwave powers and the three loading levels. These figures show the equilibrium moisture content (0.08 g w/g d. m.) for mint leaves. Using microwave drying, this required a range of between 205 and 5 minutes at five power levels (180, 360, 540, 720 and 900 W), with three loading levels (5, 1.25 and 0.5 kg/m^2). This method had a longer drying time due to the following reasons: low power (180, 360 W) and high load (5 kg/m^2), with the microwave operating at on/off intervals of nine seconds.

The data obtained were compared to previous studies. Özbek and Dadali (2007) and Arslan et al. (2010) reported that the time taken to reduce the moisture content of mint leaves to 0.054 d. b. by microwave drying was 5.3 minutes.

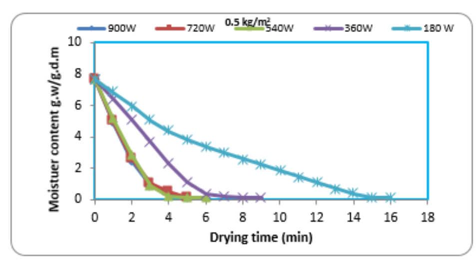
Fig. 2. Moisture degradation during microwave drying



(a)



(b)



(c)

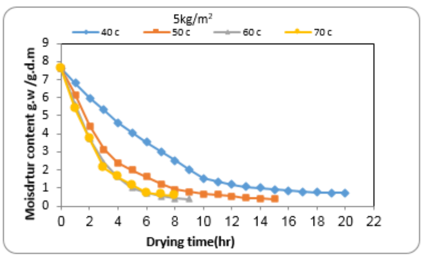
4.1.2. Oven drying

The influence of oven drying conditions (temperature and loading) on the moisture content of mint leaves is illustrated in Fig. 3 (a, b and c). Table 2 presents the final drying time (hr.) and equilibrium moisture content for different treatments with oven and solar dryers. A significant difference in drying times was observed between drying at 40 °C and at 60 and 70 °C. The drying time at 70 °C was 60%, 50% and 50% shorter, respectively, compared with the drying time at 40°C with loading levels of 5, 1.25 and 0.5 kg/m^2. Meanwhile, there were no significant differences in drying times at 50, 60 and 70 °C with loading levels of 0.5 and 1.25kg/m^2. The drying times obtained in the present study were compared with the results obtained in previous studies. Arslan et al. (2010) found that the time taken to reduce the moisture content of mint leaves to 0.046 d. b. by oven dryer was nine hours.

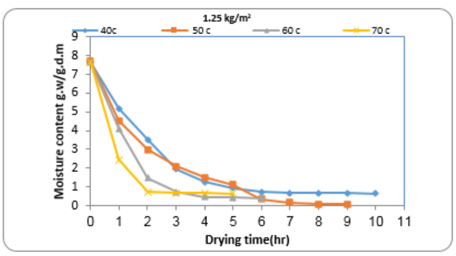
Table 2. Drying time (hr.), equilibrium and final moisture content (g. w./g d. m.) for oven and solar dryer respectively.

Loading (kg/m^2)		Drying methods					
		Oven drying temp. °C				Solar drying	
		40	50	60	70		
5	Time(hr.)	20	15	9	8	Time(hr.)	14
	Equilibrium m.c g.w./g.d.m.	0.14	0.128	0.124	0.12	Final m. c. g.w./g.d.m.	0.13
1.25	time(hr.)	10	9	6	5	Time(hr.)	8
	Equilibrium m. c g.w./g.d.m.	0.12	0.115	0.11	010	Final m.c. g.w./g.d.m.	0.117
0.5	time(hr.)	10	7	6	5	Time(hr.)	8
	Equilibrium m. c. g.w./g.d.m.	0.12	0.113	0.113	0.09	Final m. c. g.w./g.d.m.	0.118

Fig. 3. Moisture degradation during oven drying



(a)



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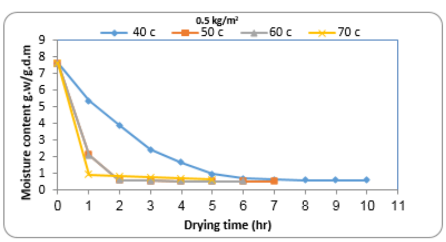
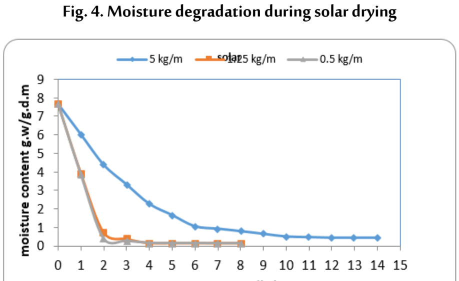


(c)

4.1. 3. Solar Drying:

Fig.4 shows the solar drying curves of moisture content versus drying time at three levels of loading. To achieve the safe storage moisture content for mint leaves, solar drying required 14, 8 and 8 hours, at three levels of loading: 5, 1.25 and 0.5 kg/m^2, respectively. The results clearly show no differences in drying times between loading levels of 0.5 and 1.25 kg/m^2. This represents a drying time 43% shorter than the drying time at 5 kg/m^2, meaning that the loading level of 1.25 kg/m^2 was optimum. Akpinar (2010) reported that the time taken to reduce the moisture content of mint leaves in a cabinet dryer, from the initial 6.14 g.w/g.d.m. to 0.05 g.w/g.d.m., was 210 minutes.

Fig. 4. Moisture degradation during solar drying

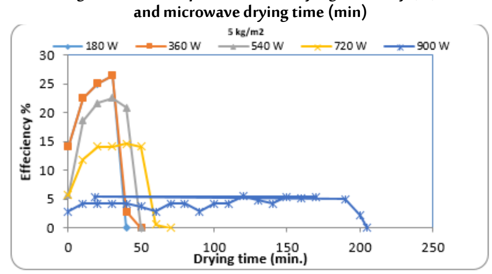


4.2. Influence of Drying Methods on Drying Efficiency

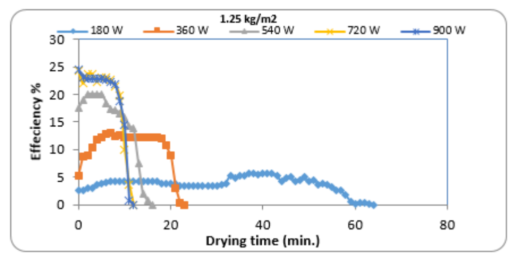
4.2.1. Microwave drying

Figure 5 (a, b and c) shows the relationship between drying efficiency and drying time, with various microwave power levels (180, 360, 540, 720 and 900 W), at three levels of loading (0.5, 1.25 and 5 kg/m^2). The drying efficiency was always relatively high at the beginning of the drying time due to an increase in drying rate. The results show that the efficiency decreased as loading rate increased, and microwave power decreased. The highest efficiency was 31%, at a loading level of 0.5 kg/m^2 with 900 W power, and the lowest was 5%, at a loading level of 5 kg/m^2 with 180 W power. Furthermore, the highest loading rate (5 kg/m^2) took the longest time, and therefore more energy consumption.

Fig. 5. Relationship between the drying efficiency (%) and microwave drying time (min)



(a)



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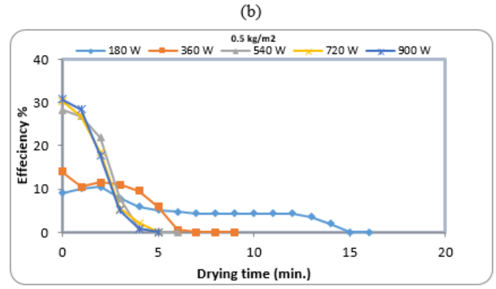
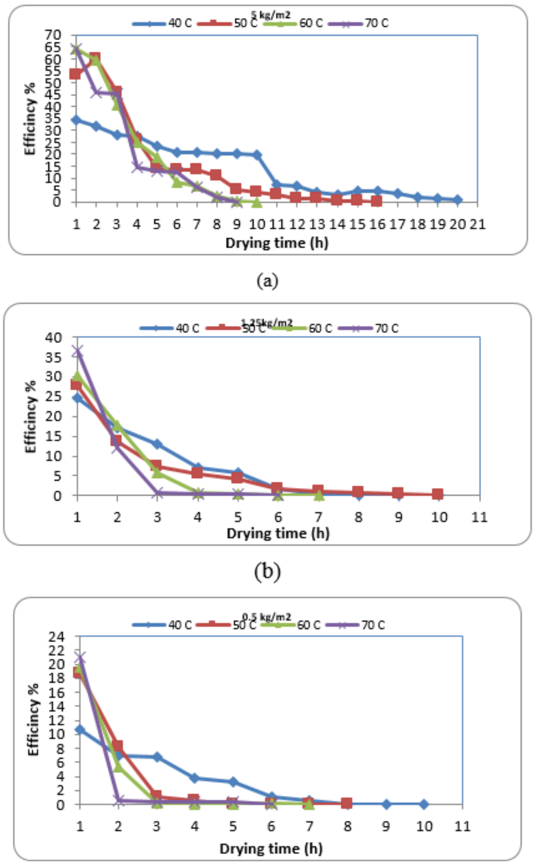


(c)

4.2.2. Oven drying

Figure 6 (a, b, and c) shows the relationship between the drying efficiency and oven drying time, with three levels of loading (5, 1.25, and 0.5 kg/m^2), and different temperatures (40, 50, 60 and 70°C). The drying efficiency was always relatively high at the beginning of the drying process due to an increase in drying rate. It can be seen that the efficiency increased as the loading rate increased, with the highest efficiency being 64% with a loading rate of 5 kg/m^2 and 70 °C . The lowest efficiency was 10% with a loading rate of 0.5 kg/m^2 and 40 °C. However, increasing the loading rate to 5 kg/m^2 took the longest time, and therefore more energy consumption.

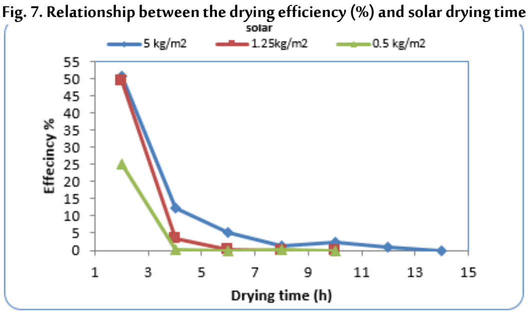
Fig. 6. Relationship between the drying efficiency (%) and oven drying time



4.2.3. Solar drying

Fig 7 describes the relationship between the drying efficiency and solar drying time. The highest efficiency was 50%, at loading rates of 5, 1.25, and 0.5 kg/m^2. Meanwhile, the lowest efficiency was 25% at a loading rate of 0.5 kg/m^2. The drying efficiency was always relatively high at the beginning of the drying process, due to an increase in drying rate.

Fig. 7. Relationship between the drying efficiency (%) and solar drying time



4.3. Influence of Drying Methods on Energy Consumption:

Table 3 shows the energy consumption for the different methods of drying peppermint (oven drying, microwave drying and solar drying). The highest value of energy consumption was 48.7 MJ at a temperature of 40 °C, with a loading rate of 5 kg/m^2 using the oven drying method. The lowest value was 0.405 MJ, using microwave power of 900 and 720 W, with a loading rate of 0.5 kg/m^2.

Table 3. Total energy consumption during the peppermint drying process using different drying methods (MJ)

Loading (kg/m^2)	Drying methods									
	Oven temperature (°C)				Solar drying	Microwave power (W)				
	40	50	60	70		180	360	540	720	900
5	**48.7**	**41.7**	**28.2**	**27.8**	**17.5**	**16.6**	**5.7**	**3.9**	**3645**	**3.240**
1.25	**24.3**	**25034**	**18775**	**17.4**	**11.09**	**5.184**	**1.8**	**1.2**	**972**	**0.972**
0.5	**20.8**	**17.03**	**16.7**	**15.6**	**11.09**	**1.296**	**0.729**	**0.486**	**0.405**	**0.405**

4.4. Influence of Drying Methods on the Essential Oil Yield:

Table 4 shows that the essential oil yield of mint leaves is significantly affected by the method of drying (microwave drying, oven drying and solar drying) at the three loading levels (5, 1.25 and 0.5 kg/m^2).The highest oil yield (1.116 ml/100 g dry weight) was obtained from a fresh sample plant. Drying the mint leaves using an electric oven (50°C and 1.25 kg/m^2 loading level) reduced the yield to 0.68 ml/100 g d. w., and increasing the drying temperature and loading to 70 °C and 5 kg/m^2 decreased the oil yield to 0.08 ml/100 g d. w. Using direct solar drying, the highest yield was 0.60 ml/100 g d. w. at 1.25 and 0.5 kg/m^2 loading levels. The essential oil content of mint leaves was completely lost when the leaves were dried using a microwave (except the leaves dried at 360 W with 1.25 kg/m^2 loading, which contained only 0.04 ml/100 g d. w.). The samples dried in the oven at 40 and 50 °C, and those which were solar dried, retained 0.62, 0.68 and 0.60 ml/100 g d. w., respectively, of essential oil. No clear differences were observed between the three treatments. However, oven drying at 60 and 70 °C retained 0.20 and 0.14 ml/100 g d. w., respectively, at all loading levels. The highest essential oil yields were obtained by using the oven drying method at 50°C. Regarding microwave drying, the high temperature resulting from microwave energy decreased the essential oil yield. This may be due to the biological structure of the oil glands of medicinal and aromatic plants. At high temperatures, these can be affected, and the epithelial cells in the dried samples of some sensitive plants have been shown to have collapsed (Venskutonis, 1997; Hamrouni-Sellami et al., 2011; Rahimmalek and Goli, 2013).

Table 4 Influence of drying methods on the essential oil yield (ml/100 g dry weight)

Tret Loading	Frish	Oven temperature (°C)				Solar drying	Microwave power (W)				
		40	50	60	70		180	360	540	720	900
5kg/m^2	1.11	0.44	0.48	0.12	0.08	0.4	0	0	0	0	0
1.25k g/m^2	1.11	0.62	0.68	0.2	0.14	0.6	0	0	0	0	0
0.5kg/m^2	1.11	0.6	0.66	0.2	0.15	0.6	0	0	0	0	0

4.5. Influence of Drying Methods on Total Chlorophyll Content:

Table 5 shows how drying methods and loading levels affect colour change. The impact on colour change of oven dried mint leaves was increased when the temperature was increased from 40– 50 °C to 60–70 °C (Maharaj and Sankat, 1996). From Table 5, the chlorophyll levels (a and b) of dried mint leaves were higher using microwave drying than the other drying methods used in this study. This could be due to the relatively short drying time when using the microwave method.

Table 5. Chlorophyll (a, b) content in mint leaves mg/L

Loading (kg/m^2)	Chlorophyll a, b	Fresh	Drying methods									
			Temperature (°C)				Solar	Microwave drying (W)				
			40	50	60	70		180	360	540	720	900
5	Ch. a	42	9	10	7	6	8	21	16	14	13	13
	Ch. b	24.6	3	4	2	2	3	7.8	5	4	3	3
1.25	Ch. a	42	14	15	11	10	11	26	27	24	22	21
	Ch. b	24.6	4	5	3	2	5	12	11	10	8	8
0.5	Ch. a	42	13	14	10	9	12	25	26	23	20	20
	Ch. b	24.6	4	5	3	3	5.6	11	10	10	7	7.5

4.6. Mathematical Model of Drying Curves:

The predicted MR of the mint was obtained using the data fit computer programme. The values of R^2, χ^2 and MBE for the models ranged from 0.99782 to 0.9999964, 2.97257E-9 to 2.46666E-4 and 5.08333E-5 to 0.18236036, respectively. For oven and solar drying, the Midili-Kucuk model showed good agreement with the experimental data and gave the best result at 70 ºC with a loading rate of 0.5 kg/m^2. The values of R^2, χ^2, and MBE for microwave drying were 0.992399 to 0.99992, 3.964E-9 to 0.00673 and 0.003233 to 0.0117096, respectively. The logarithmic model showed good agreement with the experimental data and gave the best result at 900 W of microwave power and a loading rate of 5 kg/m^2.

5. Conclusion

Solar drying is more suitable for drying medicinal plants, because it retains much of the oil and is low in cost. Oven drying (at 50 ºC and loading rate of 1.25 kg/m^2) could be another potential method of drying mint leaves, since much of the essential oil is still retained. The results showed that as microwave drying uses high temperatures, it is not suitable for drying medicinal and aromatic plants in order to obtain aromatic oils. This is due to the sensitivity of aromatic oils to heat, which can remove them entirely. Other possible experimental conditions may improve the characteristics of dried peppermint when the microwave drying method is used.

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