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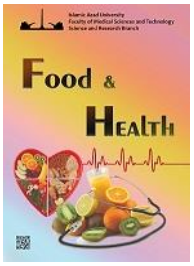

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Effects of shade and solar drying methods on physicochemical and sensory properties of *Mentha piperita* L.

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ABSTRACT

Mentha piperita L., known as mint or peppermint used extensively in the food, pharmaceutical, and cosmetics industries. Although different techniques have been studied for drying mint leaves, there is not enough information on solar drying of peppermint (especially the Persian variety) in the literature. In this study, thin layers of peppermint leaves were dehydrated evenly with three methods of shade (MI), sun (MII), and solar heat collector (MIII). The air temperature rise and drying time in I, II, and III were (1, 5, and 18ºC) and (880, 300, and 150 min), respectively. The particle size, porosity, and rehydration rate of peppermint dried in III were significantly higher than those dried with I and II. While the overall color (ΔE) of peppermint dried in I and III did not change, the greenish index and chlorophyll of peppermint dried in II were ~21% and ~15% less than those in III because it was exposed to direct sunlight radiation. The peppermint dried with III had lower bulk density, higher sensory attributes (minty aroma, flavor, cooling mouthfeel, and visual color), and overall acceptance scores than II and I. The solar dryer produced high quality dehydrated peppermint with renewable energy and without environmental contamination.

1. Introduction

During recent years, the consumption of herbal plants got more attention because of their natural flavors. While synthetic flavors may generate various health disorders, various mint products have been used for the treatment of muscle pain, irritable bowel syndrome, nerve pain, and relief from itching (1). The abundant herbal plant of mint or peppermint (known as *Mentha piperita* L.) is popular for its fresh flowering plant, dried leaves, and essential oil, which is used extensively in the food, pharmaceutical, and cosmetics industry (2). Different compounds of this herbal plant including menthol, menthone, (+/-)-menthyl acetate, 1,8-cineole, limonene, beta-pinene, and beta-caryophyllene (3), act as a carminative, cholagogue, antibacterial, secretolytic and cooling agent, and it has been used to cure different diseases (4, 5). Peppermint oil has moderate antibacterial effects against both gram-positive and gram-negative bacteria. Peppermint also possesses antioxidant, antiviral, and fungicidal activities (2, 6). On the other hand, the contents of these functional compounds are extremely dependent on weather conditions, geographical location, and post-harvest operations (7). Among different post-harvest processes (including handling, transportation, washing, size reduction, storing conditions, and packaging), drying is the critical process for producing high-quality peppermint leaves as a medicinal herb. Since the moisture content of harvested peppermint leaves changes between 75-80% (wet bases), it is necessary to reduce it to a low level (<10%). The low moisture content will protect peppermint's organoleptic properties, medicinal values, and prevent its enzymatic activity during storage and distribution (8). Usually, traditional (sunlight and shade) and industrial methods are used to dry herbal plants in many countries. Since the traditional drying of the aromatic plant is a very slow process (typically takes 2-3 days depending on the weather conditions), it is not easy to control

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its final moisture content because of changes in weather conditions. In this method, the dried peppermint leaves have low quality due to their contamination with dust, dirt, rain, animals, birds, rodents, insects, and microorganisms during drying (9). On the other hand, industrial drying requires high processing costs, generates greenhouse gas emissions (especially CO_2 emission) because of burning fossil fuels, and consumes significant amounts of energy to heat and move the airflow (9). Solar drying is a safer and more efficient method than industrial and traditional drying methods. It improves the quality of the final product, reduces production cost without generating greenhouse gas damaging the global environment (10). Morad et al. (11) reduced the drying time of peppermint leaves by up to 30% when they used a solar-tunnel greenhouse dryer (with forced air convection mode) instead of a sun dryer in similar conditions. Sallam et al. (12) employed two similar prototype solar dryers (direct and indirect) to dehydrate the whole mint (stem and leaves) under natural and forced convection. They showed that the solar drying rate of mint furnished with forced air convection was higher than the similar system with natural air convection, especially during the first few hours of drying. El-Sebaii and Shalaby (13) investigated an indirect mode forced convection solar dryer for drying mint. The results illustrated that the drying process of mint leaves was done at temperature between 39-54ºC for 5 h. Akpinar (14) dried mint leaves within 3.5 h and 6.5 h in the solar dryer with forced convection and under the open sun with natural convection, respectively. The sun drying period of mint in the temperature ranges of 30-46ºC is much longer (>2 times) than solar drying (depends on the fresh product specifications, drying, and environmental conditions). Doymaz (15) dried mono-layer of mint leaves in a solar cabinet dryer at temperature range of 35-60ºC and reported that the drying time diminished from 10 to 1.5 h. Müller et al. (16) used a greenhouse-type solar dryer for multi-layers of mint with temperature range of 40-60ºC and spent 3-4 days to reduce its initial moisture content of 80% to less than 11% wet bases (WB). Since this valuable herbal plant is grown extensively in different parts of Iran, it was our main objective to dehydrate the fresh peppermint leaves in a solar drying system furnished with a double-pass collector but without using auxiliary heat, and then compare its physicochemical and sensory properties with those dried with traditional (sun and shade) methods.

2. Material and methods

2.1. Preparations and dehydrating methods

Fresh peppermint leaves (*Mentha piperita L.*) with the average moisture content of ~77% (WB) were harvested daily from the farm in the Jovein (a city in Khorasan Razavi province), and its moisture content measured by hot air convective oven (model UNE 400 PA, Schwabach, Germany) at 105ºC for 24 h by using AOAC Method 934.06 (17). The handpicked peppermint leaves were washed and placed in sealed plastic containers and stored temporarily in a refrigerator (Daewoo, FRS-2411S, Korea) at 4ºC for 4 h. About 2.5 kg of cleaned peppermint leaves were firstly conditioned to room temperature (for ~2 h) and then dried with each of the three methods described as follows.

2.2.1.Shade drying

Layers of fresh peppermint leaves (with bed thickness of ~2 cm) extended on a cotton cloth (with a mass density of ~1.4 kg/m^2), and subjected to ambient air drying for ~14 h to obtain almost constant weight. According to the local weather station, the average values of wind velocity, ambient air temperature, and relative humidity during drying time were 3 m/s, 32.7ºC, and 12.7%, respectively.

2.2.2.Sun drying:

Layers of fresh peppermint plants (with bed thickness of ~2 cm) were extended on a cotton cloth (with mass density of ~1.4 kg/m^2), and subjected to sunlight drying for 5.5 h to obtain almost constant weight. According to the local weather station, the average values of solar radiation, ambient air temperature and relative humidity during drying time were 957 W/m^2, 29.1ºC and 23.9%, respectively.

2.2.3.Solar drying

Five trays of drying chamber covered with layers of the fresh peppermint leaves (with bed thickness of ~2 cm and mass density of ~1.4 kg/m^2) and dried with ambient air heated by the solar collector. The solar drying was completed within 2.5 h during the sunlight hours. The average value of solar radiation in accordance with the local weather station was recorded 860 W/m^2. Also, temperature changes in the different parts of the solar dryer are shown in Table 1. After the dehydration stage, they are packed and sealed in plastic containers and stored in a dry place before further quality evaluation. It should be noted that the freshly harvested and cleaned peppermint leaves were dehydrated continuously with three methods including shade area from 8:30 AM to 10:00 PM, under direct sunlight, and in the solar system both from 8:30 AM to 3:00 PM for 5 days (May 28th to June 5rd 2016). The experimental location of this study has latitude 36° 13´N and longitude 57º 37´E.

2.2.4.Specifications for solar dryer

The solar system (designed and constructed in this research) had a finned double-pass flat collector, a drying chamber with five trays; a centrifugal fan, fitting and connection pipes, and an electrical controlling system (Fig. 1). The body of the solar collector with external dimensions of 1.50 m (long)×0.95 m (wide)×0.17 m (height) was made from MDF (medium-density fiberboard). The collector had a transparent glass cover with 4 mm thickness. A black-painted white galvanized plate with 1 mm thickness inserted below the glass cover to improve heat absorption of solar radiation. As shown in Fig. 1, the heat absorber plate had eight identical fins (with L=50 cm and h=4

Table 1. Specification of different drying methods used for peppermint dehydration.

Drying methods	Description of drying method
Shade drying	Layers of fresh peppermint leaves (with bed thickness of ~2 cm) extended on a cotton cloth (with mass density of ~1.4 kg/m^2), and subjected to ambient air drying for ~14 h to obtain almost constant weight. According to the local weather station, the average values of wind velocity, ambient air temperature, and relative humidity during drying time were 3 m/s, 32.7ºC, and 12.7%, respectively.
Sun drying	Layers of fresh peppermint plants (with bed thickness of ~2 cm) were extended on a cotton cloth (with mass density of ~1.4 kg/m^2), and subjected to sunlight drying for 5.5 h to obtain almost constant weight. According to the local weather station, the average values of solar radiation, ambient air temperature, and relative humidity during drying time were 957 W/m^2, 29.1ºC, and 23.9%, respectively.
Solar drying	Five trays of drying chamber covered with layers of the fresh peppermint leaves (with bed thickness of ~2 cm and mass density of ~1.4 kg/m^2) and dried with ambient air heated by the solar collector. The solar drying was completed within 2.5 h during the sunlight hours. The average value of solar radiation in accordance to the local weather station was recorded 860 W/m^2.

Fig. 1. The actual view of solar drying system: (1) centrifugal fan, (2) drying chamber, (3) solar collector, and (4) trays.

cm) with 15 cm spacing from each other (to reduced air stream and absorb more heat from the absorber plate). Moreover, seven similar obstacles (or fin) with 15 cm spacing from each other (with L=50 cm and h=6 cm) were inserted below the heat absorber plate to increase the retention time of the air stream and absorb more heat from the bottom of the absorber plate (Fig. 2).

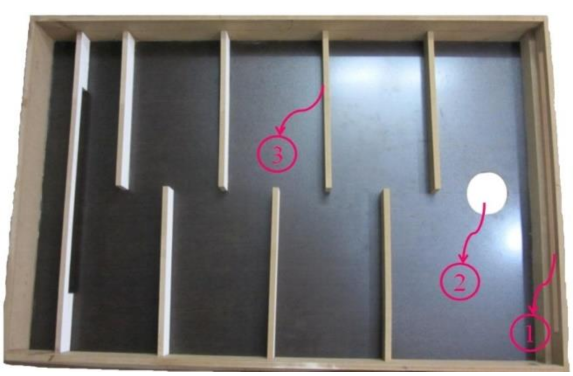

Fig. 2. The actual view of double-pass solar collector frame: (1) entrance air on the absorber plate, (2) output air from the below part of absorber plate or entrance air to drying chamber, and (3) obstacles (fins) installed on the below part of absorber plate.

The collector's tilt and orientation were determined from Equation 1 (18).

$$\beta = (\Phi - \delta) = \left(\Phi - 23.45\, sin\left[\frac{360}{365}(284 + N)\right]\right) \qquad (1)$$

where, β is the angle of the solar collector with the horizontal plane (º), Φ is latitude degree (º), δ is declination angle (º) with the south direction and N is the number of the day (in the January N=1 and in December N= 365). In order to receive maximum sun radiation and heat energy, the solar collector faced inclined to the south with a 40º angle (based on the harvesting time of peppermint leaves). The external body of the drying chamber was made from a white galvanized sheet with a thickness of 0.6 mm. The external dimensions of the chamber were 1 m (long)×0.65 m (wide)×0.65 m (height). In addition, the inner side of the drying chamber was coated with a white galvanized sheet with a thickness of 0.6 mm to prevent rusting. The outside of the drying chamber was insulated with 3 cm thickness of glass wool to decrease heat transfer rate and minimize the heat loss. Five constructed trays were (0.59 m long×0.59 m wide×0.04 m height) inserted inside the drying chamber and covered with layers of fresh peppermint leaves (with bed thickness of ~2 cm and mass density of ~1.4 kg/m^2). A centrifugal fan (373 W or 0.5 hp power single-phase electric motor 220 V, 50 Hz and 2800 rpm, impeller diameter of 15 cm, the width of 5 cm and 36 blades) was installed to provide enough airflow in the drying chamber for solar drying method. In order to record thermodynamic conditions of the solar dryer, two air sensors (AM2303 sensors modules, Aosong Electronics Co., Ltd., Guangzhou, China) were installed at the input and output of the solar collector and one air sensor at the output of the drying chamber. These were then connected to a laptop computer to record the air temperature (T) and relative humidity (RH) data continuously. It should be noted that, microcontroller program is written in Code Vision AVR software version 1.23.8 and the software of solar dryer was written in Visual C#. NET 2010.

2.2. Quality parameters measurement

2.2.1.Color properties

The color attributes ($L*$, $a*$, and $b*$ values) were measured by an Image J software version 1.48. A wooden box with white interior walls and a fluorescent lamp (12 watts) used for measuring the color properties of fresh and dehydrated plant materials (9). A digital Canon camera (Canon, SX230 HS, Japan) employed to take photos of prepared samples and transfer them to a computer equipped with color determination software. Three color parameters of plant materials including, "a^*" (redness), "b^*" (yellowness) and "L^*" (lightness) were measured in ranges of -120 (greenish) to +120 (reddish), -120 (bluish) to +120 (yellowish), and 0 (black) to 100 (white), respectively. Equation 2 was used to calculate the color change (ΔE) of peppermint leaves dried with different methods.

$$\Delta E=\sqrt{((\Delta L)^2+(\Delta a)^2+(\Delta b))^{2}} \quad (2)$$

where, ΔL is the lightness difference, Δa is the red/green difference and Δb is the yellow/blue difference (9).

2.2.2.Chlorophyll pigment

According to the method of Uribe et al. (19), a spectrophotometric methodology was used to determine the total chlorophyll content (TCC) of dried peppermint leaves. In order to extract the chloroplast pigments (i.e. chlorophyll pigments), exactly 0.1 g of finely ground peppermint leaves dried in different methods was mixed with 10 mL of ethanol 96% in falcon tubes and heated in a water bath (model E200, Lauda, Lauda-Königshofen, Germany) and shake for 20 min at 80ºC. After diluting 1 mL of each green extract with 10 mL of ethanol in new falcon tubes, about 2-3 mL of resulted extracts were transferred to spectrophotometer cells (Jenway spectrophotometer, Model 6305, Keison Products. Essex, England), separately. Then the absorbance (A) of each sample along with pure (96%) ethanol (as a blank) was read at two wavelengths (λ=645 nm and λ=663 nm) and recorded. All the determinations were performed in triplicate and Equation 3 was used to calculate the TCC.

$$TCC(mg/100\,g\,d.m.) = (20.2\times A_{645}) + (8.02\times A_{663}) \quad (3)$$

2.2.3.Moisture content

The AOAC (17) standard method No.931.04 was used to quantify the initial and final moisture content (WB) of peppermint leaves before and after drying. Equation 4 was applied to calculate the weight loss (W_l) of peppermint leaves in different drying methods.

$$W_l(\%) = (1-\frac{W_f}{W_i})\times 100 \quad (4)$$

where, W_i and W_f were the initial and final mass of peppermint leaves (g). before and after drying in each experiment, respectively.

2.2.4.Particle size, bulk density, and porosity

One hundred fragments of peppermints were dried with shade drying, sun drying, and solar drying picked randomly. After measuring their longest and shortest dimensions by using a caliper, their averages were recorded. After determining the mass and volume of each sample, Equation 5 (10) was used to calculate its bulk density (ρ_b).

$$\rho_b(kg/m^3) = \frac{m_b}{V_b} \quad (5)$$

The volume and mass of peppermint samples were determined respectively by their liquid (ethanol) displacements and an analytical balance, and the porosity (Ψ) of each sample obtained by using Equation 6.

$$\psi(\%) = \frac{V_a}{V_b}\times 100 \quad (6)$$

where, V_a, m_b, and V_b were the total volume of air within the particles, mass, and volume of peppermint leaves, respectively.

2.2.5.Rehydration rate

According to the method described by Therdthai and Zhou (20), 10 g of dried peppermint leaves was immersed in 80 g distilled water (with ratio 1 to 8) at 30ºC for 15 min. Equation 7 was used to calculate the rehydration ratio of each sample.

$$RR(g/g) = \frac{W_r}{W_d} \quad (7)$$

where, W_d and W_r were the mass of each sample (g) before and after rehydration.

2.3. Sensory evaluation

A panel of 8-trained panelists was selected among the Ph.D students and university staff of Department of Food Science, Science and Research Branch, Azad University based on their experience in sensory analysis. According to Sárosi *et al.* (21) methods, panelists scored sensory attributes (minty aroma, cooling mouthfeel, flavor, brittleness, and visual color) and overall palatability of peppermint leaves. They used the 5-point hedonic scale of 1 to 5 respectively for extremely dislike, dislike, inert, like, and extremely like to score each sensory attribute and the total scores considered for a final appraisal. All samples and palate cleansers were at ambient temperature.

2.4. Data analysis

All experiments were performed with at least triplicate (refer to the relevant table) and the results were expressed as the mean ± standard deviation. The results were evaluated using one-way analysis of variance (ANOVA) procedure at a significance level of 0.01 in Statistix software (version 8). The least significant difference (LSD) test was used for comparing the differences among the mean values.

3. Results and discussion

3.1. Drying kinetics behavior

Fig.3 and Table 2 shows the variation in the thermodynamic conditions of drying air used to dehydrate freshly picked peppermint leaves in shade drying, sun drying, and solar drying. While the averages of ambient air temperatures for methods of sun drying and solar drying were almost close to each other, they had respectively few degrees lower and higher than the shade drying. The ambient air temperature in solar drying increased (more than ~31%) and reached to (average of) 56ºC at the output of solar collector (Table 2). While the temperature difference (ΔT) of ambient air and peppermint leaves in sun-drying after absorbing daily sun heat was very low (~4ºC), it increased significantly and reached more than 18ºC in solar drying after it passed through a double-pass collector with area of ~1.26 m^2. Mokhtarian et al. (22) obtained temperature rise in ambient air (~18ºC) when they used a porous flat collector (with a total area of 4.40 m^2) to dry pistachio nut. Akpinar (14) used a solar collector with the finned absorber and forced air convection to dehydrate a thin layer of mint leaves drying and could increase the ambient air temperature up to 20°C, which is comparable with our results.

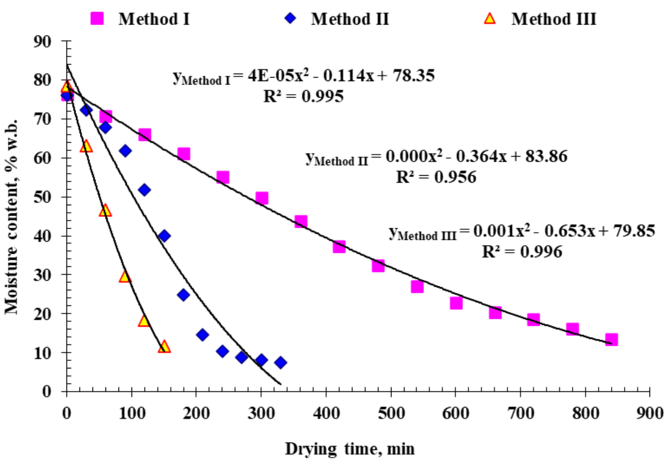

Fig. 3. The moisture reduction of peppermint versus dehydration time in different drying methods; shade drying (I), sun drying (II), and solar drying (III).

Solar radiation is one of the most important environmental parameters that it had a direct impact on rising of drying air temperature. Although the average solar heat radiation (I_{ave}) absorbed directly by peppermint leaves in sun drying was higher than solar drying, the temperature rise in solar drying was higher than the other methods and ratio of averaged ΔT to averaged solar radiation ($\Delta T/I_{ave}$) in solar drying was 5 times of sun drying (Table 1). The obtained ratio of ΔT to the surface of the collector was comparable with the previous works. While this ratio reached to ~14.3 (ºC/m^2) in our solar collector, the values of 24.6°C/m^2 and ~11.5ºC/m^2 were reported for solar drying of respectively mint leaves (14) and leafy vegetables (23). The drying times for reaching to the safe moisture content of less than ~11% WB as recommended by Müller and Heindl (24) and Doymaz (15) in shade drying, sun drying, and solar drying respectively were 880, 300, and 150 min (Fig. 3). These results showed that the shade drying and sun drying had ~82% and ~50% more drying times than solar drying, respectively. The solar thin-layer drying of peppermint leaves at 44ºC reduced the original moisture content to more than 66 levels (77 to 11% WB) within 150 min. However, Doymaz 15 spent 180 min at 55ºC (10ºC higher) to reduce 75 levels (84.7 to 10% WB) of the moisture content of fresh mint leaves in a cabinet dryer (equipped with electrical heater). Similarly, Müller et al. (16) spent 3-4 days at ~50ºC to reduce 69 levels (80.0 to 11% WB) of the moisture content of fresh mint leaves in a greenhouse solar dryer. Although it is possible to raise air temperature more 55ºC and reduce the drying time of peppermint leaves much lower than 150 min, it is very hard to maintain the high quality of fresh peppermint leaves in its final dried product. The air temperature of 44ºC in the drying chamber could dehydrate peppermint leaves with good sensory properties and ~20% less drying time. The drying rates of peppermint leaves dehydrated with solar drying was significantly ($p<0.01$) higher than the ones dried in other methods due to its shortest drying time (Fig. 4). The moisture content of peppermint leaves reduced from 80% WB (400% dry bases or DB) to almost 10% WB in each method and the water loss of 2.5 kg of fresh peppermint leaves during drying was ~1.95 kg. Consequently, the averaged drying rates were considerably different and became 2.2, 6.5 and 13 (g H_2O/min) for shade drying, sun drying, and solar drying, respectively. As a result, the drying rate of solar drying was ~6 and 2 times of shade drying and sun drying, respectively. Akpinar (14) and Mokhtarian et al. (9) obtained similar results when they compared solar drying systems with conventional sun dryers to dehydrate respectively mint leaves and pistachio nuts.

3.2. Particle size, porosity, bulk density, and rehydration rates

Fig. 4 shows the visual particle sizes of peppermint leaves dried with each method. While, ~70% of particle sizes of

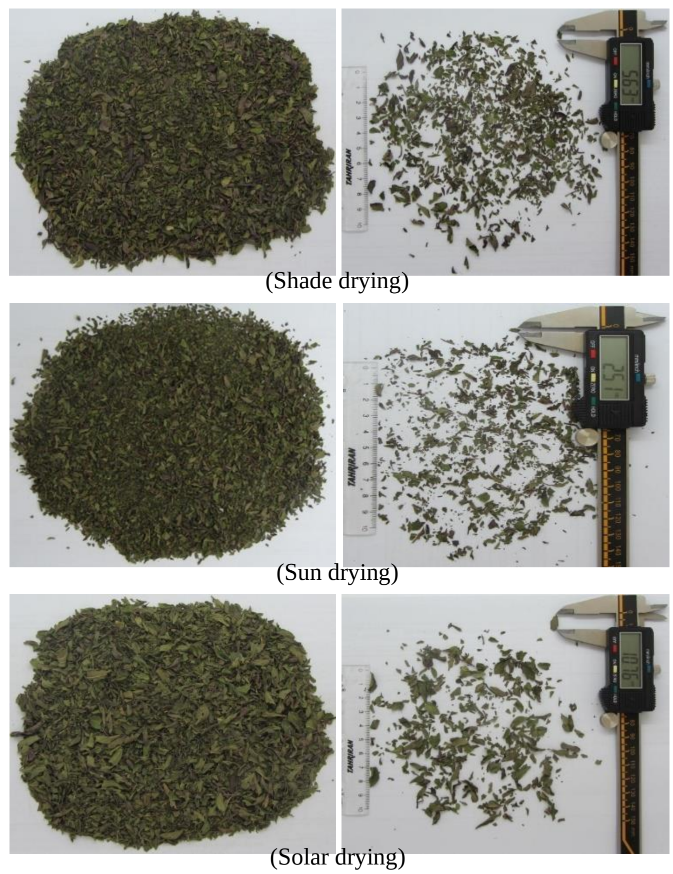

Fig. 4. The actual views and sizes of peppermint dehydrated with shade drying, sun drying, and solar drying along with the caliper used for measuring dimensions.

peppermint leaves dried with shade drying and sun drying were in the range of their means respectively 4.64±1.80 and 2.85±1.25, more than 80% of particles in peppermint leaves dried with solar drying were in range 8.81±1.76 (Table 2). The porosity of fruit and vegetables is affected by moisture loss during dehydration. Our results showed that the low porosity of fresh peppermint leaves with high moisture content (80% WB) increased substantially and reached up to 85%. The porosity of apple slices increased from 20 to 60% when its moisture content decreased from 85%to ~10% during dehydration (25). Since the particle size of peppermint leaves dried with solar drying was three times of similar samples dried with sun drying, it had significantly more porosity and less bulk density than those in

Table 2. Comparison of averaged air-drying parameters of peppermint dehydrated with different methods.

Drying Parameter	Drying Methods			Parameter Ratios (Solar drying/Sun drying)
	Shade drying	Sun drying	Solar drying	
Ambient air temperature during drying T_a, (ºC)	32.7	29.1	38.56	~1.32
Air temperature at the output of collector, $T_{c,i}$ (ºC)	–	–	~56	–
Air temperature for drying of peppermint $T_{dc,i}$ (ºC)	–	33	44	~1.33
Air temperature at the exhaust of drying chamber, $T_{dc,o}$ (ºC)	–	–	~40	–
Solar radiation I, (W/m^2)	–	957	860	~0.899
Ambient Air temperature rise due to sun and solar drying ΔT (ºC)	–	~4	~18	4.5
$\Delta T/I_{ave}$ [(m^{2o}C)/W]	–	0.0042	0.021	5
$\Delta T/A$ (ºC/m^2)	–	–	14.29	–

sun drying (Fig. 4 and Table 3). The dimensions (particle or granule size) of agricultural products have considerable effects on their bulk density. When the particle size of mango powders decreased, its porosity and bulk density decreased and increased, respectively (26). Since the moisture content (WB) of peppermint leaves dried with three methods were almost even, these results may be attributed to the decrease in the inter-particle voids of smaller sized particles with larger contact surface areas per unit volume. The weight loss in the final product of sun-drying was higher than the similar ones in solar drying (77.53 versus 75.63%) however, their differences were significant ($p<0.01$). Conversely, the rehydration rate values of peppermint leave dried in shade drying and solar drying were significantly greater than the sun drying (Table 3).

Table 3. Dimensions, frequency, and porosity of peppermint particles obtained from each of the drying methods.

Particle Size and porosity	Shade drying	Sun drying	Solar drying
Relative frequency for < 1.5 mm	1	12	1
Relative frequency for 1.5 to 3 mm	20	42	1
Relative frequency for 3 to 4.5 mm	36	32	1
Relative frequency for 4.5 to 6.5 mm	26	12	4
Relative frequency for 6.5 to 8 mm	12	1	34
Relative frequency for > 8 mm	5	1	59
Number of particles	100	100	100
Ave. of particle sizes (mm) ± SD	**4.64±1.80**	**2.85±1.25**	**8.81±1.77**
Porosity replicate I (%)	80.0	69.3	86.7
Porosity replicate II (%)	78.7	68.0	82.7
Porosity replicate III (%)	77.3	68.0	84.0
Ave. of porosity (%) ± SD	**78.7±1.33**	**68.4±0.77**	**84.4±2.04**

Although the air temperature of solar drying was higher than the air in sun drying, the direct heat (solar radiation) and product temperature of solar drying was lower than sun drying. In other words, direct heating and high product temperature cause more shrinkage and case hardening which causes less water rehydration. Therdthai and Zhou (20) used scanning electron micrographs for mint leaves dried by different modes and concluded that the mint dried with direct heat had less porous structure after dehydration. The spearmint samples dried with indirect heat along with high convective air temperatures (>45ºC) and flow, gain more water, and maintained hard, solid surface and shrunken, packed structure until the end of their rehydration process (27).

3.3. Total chlorophyll

The amount of chlorophyll remained in the dried products of green vegetables is a quality indicator of the drying method. ANOVA results showed that drying with solar drying maintained significantly ($p<0.01$) higher content of chlorophyll in the final product than the ones dried with sun drying (Table 4).

Table 4. The mean values of physicochemical properties of peppermint dried with different methods (averages of 3 replicates) *.

Treatments	Moisture content (% WB)	Weight loss (%)	Particle size (mm)	Porosity (%)	Bulk Density (kg/m^3)	Rehydration rate (g/g)	Chlorophyll of dried material (mg/100 g)
Fresh peppermint	76.95±0.60^a	0.0±0.0^d	NM**	NM	NM	0.0±0.0^d	NM
Shade drying	10.1±0.19^b	71.61±0.82^c	4.64±1.80^b	78.67±1.33^b	110.67±3.7^a	5.63±0.11^a	1.59±0.54^a
Sun drying	9.8±0.17^d	77.53±0.80^a	2.85±1.25^c	68.44±0.77^c	112.41±4.16^b	3.81±0.07^c	1.08±0.03^c
Solar drying	9.9±0.18^c	75.63±0.61^b	8.81±1.76^a	84.45±2.03^a	109.13±4.35^a	5.02±0.11^b	1.37±0.08^b

*Different superscripts letters in each column show the significant ($p<0.01$) differences between the treatments. **Not measured.

The drying time, drying temperature, light, and oxygen level play important roles in the degradation of chlorophyll pigment (20). Furthermore, Rudra et al. (28) reported that high temperature could lead to the replacement of magnesium ion in the tetra-pyrrole ring of chlorophyll by hydrogen, thereby decolorizes chlorophyll and converts it to pheophytin. Previous reports have shown that chlorophyll degradation occurred at temperatures exceeding 50°C in thyme and 60°C in broccoli juice (29). Our results showed that the lowest chlorophyll content belonged to peppermint leaves dried with sun drying, mainly because of high oxygen level and straight solar radiation (leaving more heat on peppermint leaves) during drying.

3.4. Color parameters

Statistical analysis showed that different drying modes had significant effects (p<0.01) on changing the color parameters of peppermint leaves. The lightness (L^*) values of fresh plant materials significantly reduced from a mean value of ~53 to~49 because of the dehydration process with different methods (Table 5). After the drying process, the greenish (negative a^*) and yellowish (positive b^*) indexes (absolute values) of dried peppermint leaves were decreased significantly, due to the degradation of chlorophyll pigment (19, 20). The overall color change (ΔE), which is a combination of L^*, a^* & b^* has been used extensively an index of the color's variation during fo processing. The highest ΔE (or color changes) of dried peppermint leaves was observed in sun-drying which fresh peppermint leaves had direct solar radiation and heat absorption. As a result, it more degradation of color compounds in peppermint leaves. The similar values of ΔE in peppermint leaves dried with shade drying and solar drying showed that the color quality of dried product with the the solar system was very close to those dried in the shaded area. Rudra et al. (28) stated that the degree of ΔE was dependent on drying temperature, drying time, and oxygen level.

Table 5. The mean values** (average of 7 replicates) of color attributes of peppermint dried with different methods.

Drying methods	L^*	a^*	b^*	ΔE
Fresh peppermint	53.73±2.59[a]	-8.15±0.74[c]	6.28±0.89[a]	0.0±0.0[c]
Shade drying	49.67±1.46[b]	-3.17±0.205[b]	3.64±0.39[b]	7.02±1.06[b]
Sun drying	50.80±2.52[b]	-2.30±0.63[a]	1.68±0.16[c]	8.33±0.82[a]
Solar drying	50.58±1.12[b]	-2.90±0.27[ab]	2.25±1.56[c]	7.50±1.09[ab]

**The same superscripts letters in each column are not statistically different (p<0.01).

3.5. Sensory assessment

Significant differences (p<0.01) were found for sensory properties (minty aroma, cooling mouthfeel, flavor, visual color, brittleness, and overall palatability) of peppermint leaves dried with the three methods. The characteristics of 'minty aroma' and 'visual color' are the two main factors for pricing of dehydrated peppermint leaves. Table 6 shows that the lowest sensory scores of the 'minty aroma' and 'visual color' were related to peppermint leaves dried in sun drying, most probably due to its direct irradiation during drying. Sárosi et al. (21) reported that releasing aromatic and flavor compounds along with discoloration of chlorophyll pigment increase when peppermint leaves are directly heated. Furthermore, considerable color changes will be noticed when fruits and vegetables are dehydrated at high temperatures and long time (30). The highest sensory score of 'cooling mouth feel' was observed in peppermint leaves dried with solar drying because of its high content of 'minty aroma'. This means that any agent that reduces the 'minty aroma' or menthol compound (the main component of essential oil in peppermint leaves), will lead to a reduction of this characteristic (cooling mouth feel). The 'brittleness of peppermint leaves' scores of plant materials dried with sun drying and solar drying was significantly (p<0.01) greater than the ones dried with shade drying, most probably because they absorb heat in shorter drying time than those dried in shade area. Generally, the panelists' scores showed clearly that peppermint leaves dried with the solar system had a higher overall or total palatability score (~23) in comparison with the same score for the ones dried with sun drying (~12).

Table 6. The mean values of the sensory characteristics of peppermint dried with different methods (average of 10 replicates) *.

Drying methods	Minty aroma	Cooling mouth feel	Flavor	Color	Brittleness	Overall palatability
Shade drying	3.1±0.57[b]	4.1±0.875[a]	3.7±0.67[b]	4.9±0.32[a]	1.8±0.42[c]	**17.6±1.84[b]**
Sun drying	2.3±0.67[c]	1.5±0.53[b]	1.5±0.53[c]	2.5±0.71[c]	4.0±0.47[b]	**11.8±1.13[c]**
Solar drying	5.0±0.0[a]	4.6±0.52[a]	4.8±0.42[a]	4.1±0.32[b]	4.6±0.52[a]	**23.1±0.87[a]**

*The same superscripts letters in each column are not statistically different (p<0.01).

4. Conclusion

The suggestive solar dryer was able to reduce high moisture (~77% WB) of fresh peppermint leaves to a safe level (~10% WB) with 50% lesser drying time in comparison with conventional sun drying. The suggestive solar system could increase ambient air temperature up to 18ºC (>3 times of 5ºC obtained in sun drying). It was also able to dehydrate peppermint leaves with much bigger particle size (much fewer fine particles), more porosity, and more rehydration rate. The greenish index (minus a^*) and total chlorophyll content of peppermint leaves dried with solar dryer were ~21% and ~15% more than those dehydrated with sun drying mainly because it was not exposed directly to sunlight radiation. Finally, the peppermint leaves dried with the solar system had the best sensory scores and overall acceptance in comparison with those dried in sun or shade areas.

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