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Essential oil components, antioxidant capacity, and fatty acid profile of water mint (*Mentha aquatica* L.) as affected by various drying methods

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ABSTRACT

Purpose: The drying process is an outstanding factor influencing secondary metabolites in medicinal plants. Although the impact of drying techniques has been addressed in some medicinal plants, there is limited data to describe the essential oils (EO) and fatty acids (FA) profiles in aerial parts of medicinal plants using traditional and modern drying techniques. **Research method:** This research compared the EO content and composition, antioxidant capacity, and FA profile of aerial parts of water mint (*Mentha aquatica* L.) dried using various techniques, including sun, shade, conventional oven and vacuum oven (each of them at 40, 45, and 50 °C), and microwave (200, 400, and 600 W). **Findings:** The results showed that the minimum antioxidant potential (with maximum IC50: 113 µg mL^{-1}) was reported in sun-exposed samples. At the same time, the highest EO content was found in shade-dried samples, followed by oven at 40 °C and vacuum at 40 °C. The primary EO compounds were 1,8-cineole, menthol-furan, trans-caryophyllene, germacrene D, and viridiflorol. Shade and oven drying resulted in higher monoterpenes, while vacuum and microwave drying led to elevated sesquiterpenes. Vacuum drying at 40 °C produced the highest levels of saturated fatty acids, but microwave drying, specifically at 600 W, had the highest levels of polyunsaturated fatty acids compared to other drying methods. According to agglomerative hierarchy clustering (AHC) results, fresh samples were grouped with shade-drying. **Research limitations:** There was no limitations. **Originality/Value:** The current study shows that, after suggesting shade conditions, we may use the oven at low temperature and vacuum to produce water mint products of excellent quality.

Keywords:
Linolenic acid, Monoterpenes, Palmitic acid, Sesquiterpenes, *trans*-Caryophyllene, 1,8-cineole

INTRODUCTION

Aromatic and medicinal plants (AMPs) possess remarkable pharmaceutical potential and numerous health benefits, leading to their widespread use in the pharmaceutical and food industries as natural additives and antioxidants (Anand et al., 2019). Among the most important derivatives of these plants are essential oils (EOs), which comprise a complex mixture of aromatic compounds such as terpenoid alcohols, hydrocarbons, phenols, aldehydes, esters, and ketones that contribute both to their fragrance and significant bioactive properties (Ali-Arab et al., 2022). Essential oils are recognized as potent antioxidants due to their ability to inhibit oxidation, while fatty acids (FAs) are valuable because of their nutritional roles.

Pharmaceutical, detergent, soap, lubricant, and cosmetic industries. Polyunsaturated fatty acids such as omega-3 and omega-6 are essential for human health, as they cannot be synthesized by the body (Saini & Keum, 2018). In higher plant tissues, fatty acids-predominantly palmitic, stearic, oleic, and linolenic acids-are found in varying proportions, and their types, and lipid levels differ considerably among plant organs such as seeds and leaves (Al-Hwaiti et al., 2021).

Microwave, freeze-drying, and infrared drying methods, along with vacuum drying, are emerging as novel drying methods. Studies have shown that these methods have significant effects on volatile compounds of plants of the Laminaceae family. Among them, microwave drying has provided promising results in maintaining the quality and integrity of essential oils (Żbik et al., 2023). Drying is one of the most important methods of preserving medicinal and aromatic plants (AMPs), which, by reducing the water content of plant tissues to less than 15%, inhibits microbial growth, limits biochemical changes, and maintains the quality of the final product in terms of active ingredients, aroma, and color (Nurhaslina et al., 2022). Drying also reduces the volume and weight of the product, making storage and transportation easier, and transportation easier, and increasing its shelf life. Despite the widespread use of hot air dryers, this method requires long drying periods due to the slow rate of heat transfer to the plant tissue. Such conditions can cause the destruction of active compounds as well as the reduction of nutritional content through oxidation and the activity of residual enzymes (Chua et al., 2019). Recently, innovative techniques such as microwave drying, freeze drying, infrared drying, and vacuum drying have been considered as alternatives to hot air drying. Among these methods, microwave drying is increasingly used in the processing of medicinal plants due to its rapid evaporation of water from plant tissue, significant reduction in process time, and significant savings in energy consumption (Rostami et al., 2018).

The Laminaceae family has a wide range of medicinal and aromatic species with diverse bioactive compounds. One of these species *Mentha aquatica* L, a medicinal and aromatic perennial plant that grows widely in the Caspian regions of Iran (Hassanpouraghdam et al., 2022). This plant has underground stems and erect or creeping aerial stems 20 to 90 cm high, with often hairy leaves, whose morphology can affect the drying process and the preservation of the quality of active compounds. Its essential oil mainly consists of beta-caryophyllene, viridifloral, 1,8-cineole, piperitone oxide, and menthofuran (Singh et al., 2020). The aerial parts of this plant are used in traditional medicine to treat pulmonary disorders and some digestive problems, especially due to the presence of compounds such as 1,8-cineole and menthofuran (Hassanpouraghdam et al., 2022). *Mentha aquatica* L. has various beneficial properties, including antimicrobial, anti-inflammatory, and antioxidant activities, due to its essential oils, including flavonoids and polyphenols. It is traditionally used to reduce digestive problems and respiratory disease .and due to its significant bioactive compounds and high antioxidant activity, it is used in the medical, cosmetic and health industries. It is also used as

a valuable medicinal source due to its distinctive properties (Asadollah-Pour et al., 2021; Fidan et al., 2023; Truong et al., 2022). *Mentha aquatica* L. is perennial plant growing along shallow river banks and moist meadows, used as a wild vegetable in local cooking. (Asadollah-Pour et al., 2021). And also, its essential oil is used in the confectionery and beverage industries for flavoring and producing perfume (Djamila et al., 2021).

MATERIALS AND METHODS

Plant preparation and experimental design

Leaves of flowering shoots of water mint (*Mentha aquatica* L.) were collected from their natural habitats in northern Iran Mazandaran province (52° 39′ 20″ longitude, 36° 33′ 48″ latitude).

The plant populations were identified by expert botanists, and voucher specimens were deposited in the herbarium (voucher code: 20).

This research used new and traditional drying methods. *Mentha aquatica* L. samples were subject to five different drying techniques in 12 treatments, i.e., sunlight-drying, shade-drying, conventional oven-drying (at 40, 45, and 50 °C) (Capacity 2001; Faraz Electric, Iran), vacuum oven-drying (at 40, 45, and 50 °C), and microwave-drying (at 200, 400, and 600 watts power output). The plant samples were uniformly distributed as the same according to a thin layer on a steel tray or drying racks for all drying treatments.

In order to determine the amount of instantaneous water in dried materials, 150 g of the samples were weighed and their moisture content computed using Equation (1) (Samadi et al., 2018):

$$M = \left(\frac{W_0(M_0-1)+W}{W}\right) \quad (1)$$

Where, M = the instantaneous moisture content (g water/g wet matter); W0 = the sample initial mass (g); W = the sample final mass (g). In each drying method, the drying process was continued until the moisture content of the samples reached 0.11 g $_{water}$/g $_{wet\ matter}$, which is suitable for storage and extraction of essential oil (Samadi et al., 2018).

Table 1. The physicochemical properties of the soil samples.

Parameter	Value
Organic carbon (OC %)	1.49
Total N (%)	0.12
C/N	12.43
P (mg kg^{-1})	20.5
K (mg kg^{-1})	280.3
Na (mg kg^{-1})	59.7
Ca (mg kg^{-1})	88.5
Mg (mg kg^{-1})	22.2
Fe (mg kg^{-1})	3.1
Zn (mg kg^{-1})	0.32
EC (ds m^{-1})	1.1
pH	8.3
Texture	Sandy-loam

Sun and shade drying

The heating source for sun-drying was direct solar energy. Fresh herbs were spread out on drying racks with good ventilation and exposed to the sun during sun-drying. To obtain sun-dried samples, the plants were left under direct sun/daylight at temperatures between 25-31 °C, for 3 days with about 33 h of light. In shade drying The procedure was conducted virtually identically to sun drying, except that the herbs were placed in the shade under the natural airflow at the room with sufficient ventilation, temperature (25±3 °C), low humidity (25%), and no direct sunlight exposure for 5 days (Mokhtarikhah et al., 2020). In order to uniform drying, plants were turned over every 3 h.

Oven drying

This procedure required an oven and monitored the temperature to ensure stability. Accordingly, the samples were dried at 40, 45, and 50 °C, and their weights were recorded in 20 min intervals during the drying process (Ghasemi Pirbalouti et al., 2013).

Vacuum drying

A vacuum pump (Germany) with an absolute pressure of 15 bar and a pump speed of 22 L min^{-1} provides the vacuum. A thermocouple was used to measure the temperature (40, 45, and 50°C). It was exerted by the IR lamp and changed by varying heights (Ghasemi Pirbalouti et al., 2013).

Microwave drying

The drying tests were conducted in a microwave-vacuum dryer that operated at microwave frequencies of 2450 MHz and power outputs of 200, 400, and 600 W. It included a microwave oven (2450 MHz, MCE-945G; Samsung, Seoul, South Korea). Mass transfer kinetics monitored the weight changes every 5 min for 200 W, every 2 min for 400 W, and every 0.5 min for 600 W (Mokhtarikhah et al., 2020).

Scavenging activity of the diphenyl-picrylhydrazyl (DPPH) radical

To obtain the methanolic extract, soaked 100 g of dry samples in the methanol for 48 h. The capacity of sections to reduce the radical 2,2-diphenyl-1-picrylhydrazyl (DPPH) was assessed using the instruction described by Atmani et al. (2009). It mixed 15 mL of a solution of DPPH in methanol (5 mM) with 2.45 mL of a plant extract for 30 min, and the absorbance was recorded at 517 nm (2). Ascorbic acid was used as a positive control.

$$\text{Scavenging activity of extracts (IC50)} = [A0-(A1–AS)]/A0]100 \qquad (2)$$

Where *A*0 is the absorbance of DPPH alone, *A*1 is the absorbance of DPPH + extract, and *A*S is the absorbance of the section only. The IC50 value was expressed as the amount exactly to scavenge 50% of DPPH.

Essential oil extraction

To measure the EO content, 100 g of dried aerial parts from each treatment were hydro-distilled in the Clevenger-type apparatus for 3 h and reported as a w/w percentage, using the following formula (3) (Rustaiee et al., 2011). All the EO samples were stored at 4 °C for analysis by gas chromatography (GC) and gas chromatography-mass spectrometry (GC-MS)

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$$\text{EO content \%} = \left(\frac{\text{Mass of EO obtain (g)}}{\text{Mass of dry matter (g)}}\right) \times 100 \qquad (3)$$

Gas chromatography (GC) analysis of EO

It used thermo-UFM ultrafast gas chromatograph equipment with a ph-5 fused silica column (10m length × 0.1 mm id., film thickness 0.4 µm) to identify EOs. The oven temperature was maintained at 60 ºC for 5 min and then programmed to 285 ºC at a rate of 5 ºC min^{-1}; flame ionization detector (FID). Injector temperatures were 290 ºC and 280 ºC, respectively; helium was applied as carrier gas with an inlet *pressure* of 0.5 kg cm^{-1} (Ali-Arab et al., 2022).

Gas chromatography-mass spectrometry (GC-MS)

To detect the EOs profile, GC-MS was applied and accomplished by Varian 3400 GC-MS system equipment with AOC-5000 auto-injector and DB-5 fused silica capillary column (30 m × 0.25 mm i.d.; film thicknesses 0.25 µm). The temperature was programmed from 60 to 250 °C with 3 °C min^{-1}; Injector and interface temperatures were 260 and 270 °C, respectively; the acquisition mass range of 40–340 amu; ionization voltage of 70 eV; the carrier gas was helium at a velocity of 45 *cm* sec^{-1} (Ali-Arab et al., 2022). One microliter of the sample was injected manually in the split mode 1:25 (Adams, 2005).

Compound identification

By injecting a standard of C_7-C_{25} *n*-alkanes under identical circumstances, retention indices (RI) were calculated. The EO components were identified by comparison of retention indices and mass spectra by computer library search (NISI-MS20) and available data from the literature (Adams, 2005). It obtained the area percentage electronically from the GC-FID response without using an internal standard or correction factors.

Fatty acid profile

To measure the content of fatty acid methyl esters (FAMEs) in water mint leaves, gas chromatography (model Varian CP-3800) coupled with mass spectrometry (model Agilent 5973N) was used with a capillary column DB-5MS. Helium was used as carrier gas with the pressure of 25 bar. The detector and injector temperature were 255 and 270 °C, respectively. The temperature program started from 125 °C for 0.5 min, followed by 150 °C for 2 min, and 200 °C for 90 min. 1g of powdered leaves was mixed with 15 ml distilled water and appropriate solvent, centrifuged at 2500 rpm for 10 min and the lower phase filtered. The solvent was evaporated under nitrogen, and 1 ML of the residue was injected into the GC to determine the composition and content fatty acids.

Statistical Analysis

The statistical analysis was performed in a completely randomized design (CRD) with five replicates for ten populations. Data were analyzed using SAS software version 9.2, and the mean of data was compared using Duncan multiple range test. The XLSTAT software was used to perform Agglomerative Hierarchical Clustering (AHC) based on the Ward variance technique and Principal Component Analysis (PCA).

RESULTS

Antioxidant activity

The results showed that the maximum IC50 was reported in the sun-drying method. At the same time, its minimum amount was observed in a vacuum at 50 °, with an 8.2-fold reduction relative to sun-drying (Fig. 1a). As a result, samples dried upon sun and microwave showed a higher IC50, but shade and oven-dried leaves represented the lower values of IC50 (Fig. 1a).

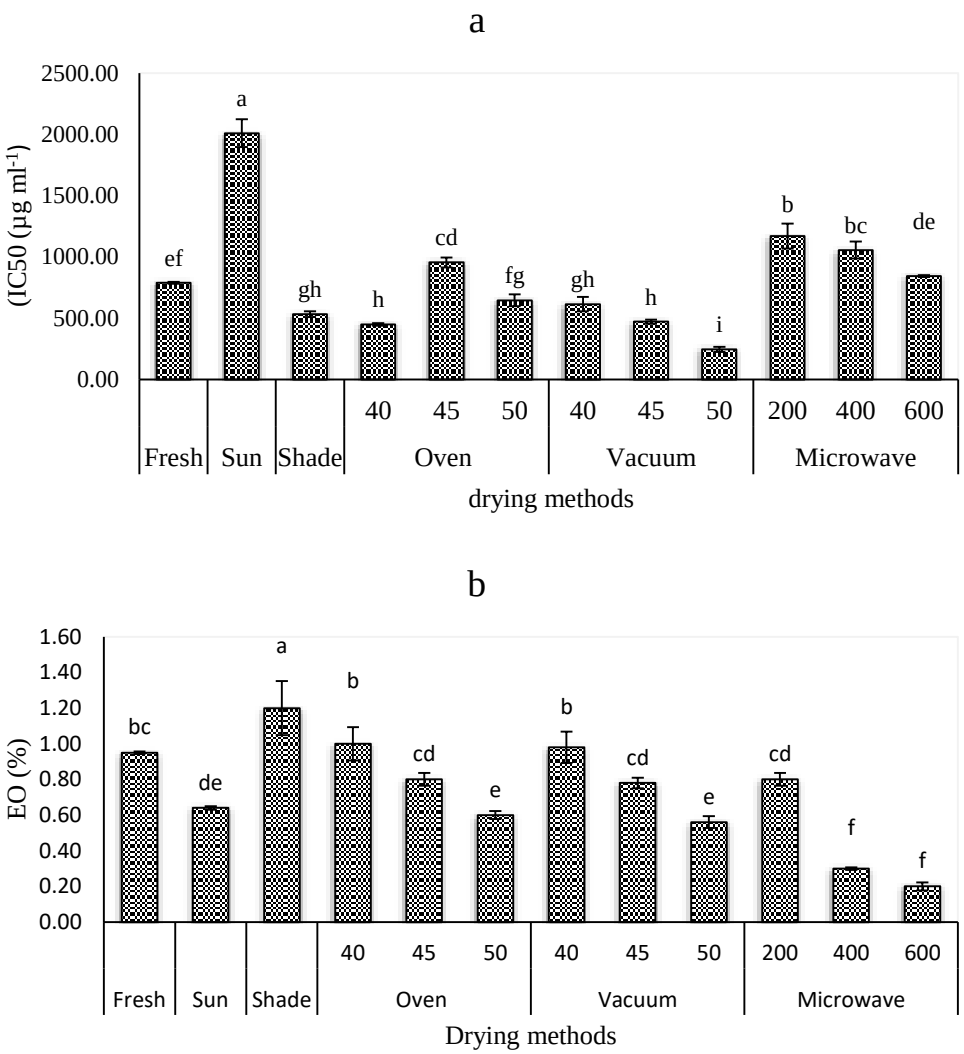

Fig. 1. Antioxidant capacity (a) and essential oil content (b) for water mint plants under different drying methods.

Table 2. Main compounds of essential oils for water mint under different drying methods.

Drying method	1,8-Cineol	Menthofuran	*trans*-Caryophyllene	*Germacrene D*	Viridiflorol
Fresh	14.2±0.74c	13.6±0.65a	11.43±0.37d	8.25±0.23e	7.31±0.01e
Sun	9.15±0.27de	7.67±0.26cde	9.88±0.67de	8.69±0.59e	8.15±0.23de
Shade	15.95±0.08b	11.55±0.5b	13.26±0.16c	9.13±0.24de	3.29±0.15g
Oven 40 °C	10.59±0.3d	8.77±0.58c	11.23±0.42d	8.97±0.28de	5.73±0.47f
Oven 45 °C	19.91±0.62a	7.07±0.09de	10.97±0.5d	8.24±0.49e	9.31±0.56bc
Oven 50 °C	9.78±0.53d	5.68±0.31fg	11.2±0.43d	11.85±0.05c	8.42±0.31cd
Vacuum 40 °C	9.19±0.7de	8.1±0.38cd	16.22±1.02b	11.59±0.25c	9.4±0.59b
Vacuum 45 °C	13.25±0.47c	6.7±0.02ef	20.29±0.46a	14.67±0.21a	7.71±0.1de
Vacuum 50 °C	8.08±0.58e	4.75±0.58g	15.3±0.75b	13.11±0.25b	7.71±0.1de
Microwave 200 W	12.78±0.33c	5.08±0.49g	11.29±0.41d	9.69±0.08d	3.14±0.11g
Microwave 400 W	10.76±0.25d	3.01±0.38h	15.78±0.89b	11.76±0.38c	15.32±0.53a
Microwave 600W	10.53±0.43d	3.48±0.28h	8.53±0.27e	5.55±0.3f	6.01±0.33f

Values are means ± standard error of the mean (SEM) of five replications (n= 5). Different letters in each column show statistically significant differences among treatments at $P \leq 0.05$.

Essential oil (EO) content and composition

It addressed the highest EO content in shade-dried samples followed by oven at 40 °C and vacuum at 40 °C. However, the minimum EO amounts were observed in microwave 400 and 600 W with four and 6-fold decreases, respectively, compared to sun drying (Fig. 1b).

The GC/MS analysis showed that the main EO compounds were 1,8-cineole, menthofuran, *trans*-caryophyllene, germacrene D, and viridiflorol (Table 2). 1.8-cineole ranged from 8.08 in vacuum 50 °C to 19.91 in oven 45 °C. The maximum menthofuran was obtained in fresh samples, followed by shade drying methods. Vacuum 45 °C showed the higher *trans*-caryophyllene and germacrene D amounts to 20.45 and 14.67% of total EO content. Monoterpene hydrocarbons showed different amounts upon drying methods, with the minimum payment in the microwave at 600 W (Fig. 2a). Oxygenated monoterpenes ranged from 13.92 in a vacuum at 45 to 40.45 °C at 50 °C (Fig. 2b). The sesquiterpene hydrocarbons were found in 14.20-41.05% of the total EO content (Fig. 3a). In comparison, the oxygenated sesquiterpenes in microwave 400 have higher than other drying treatments (Fig. 3b).

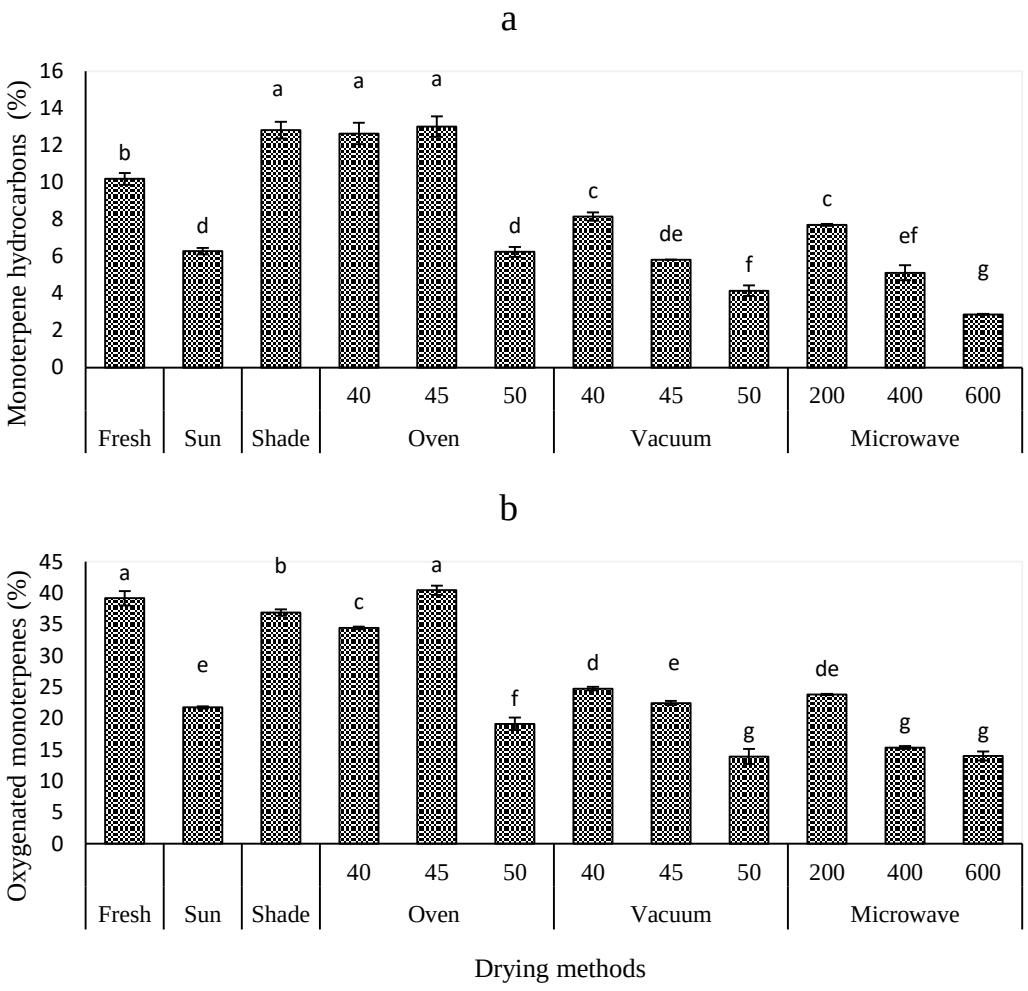

Fig. 2. Monoterpene hydrocarbons (a) and oxygenated monoterpenes (b) of essential oil for water mint plants under different drying methods.

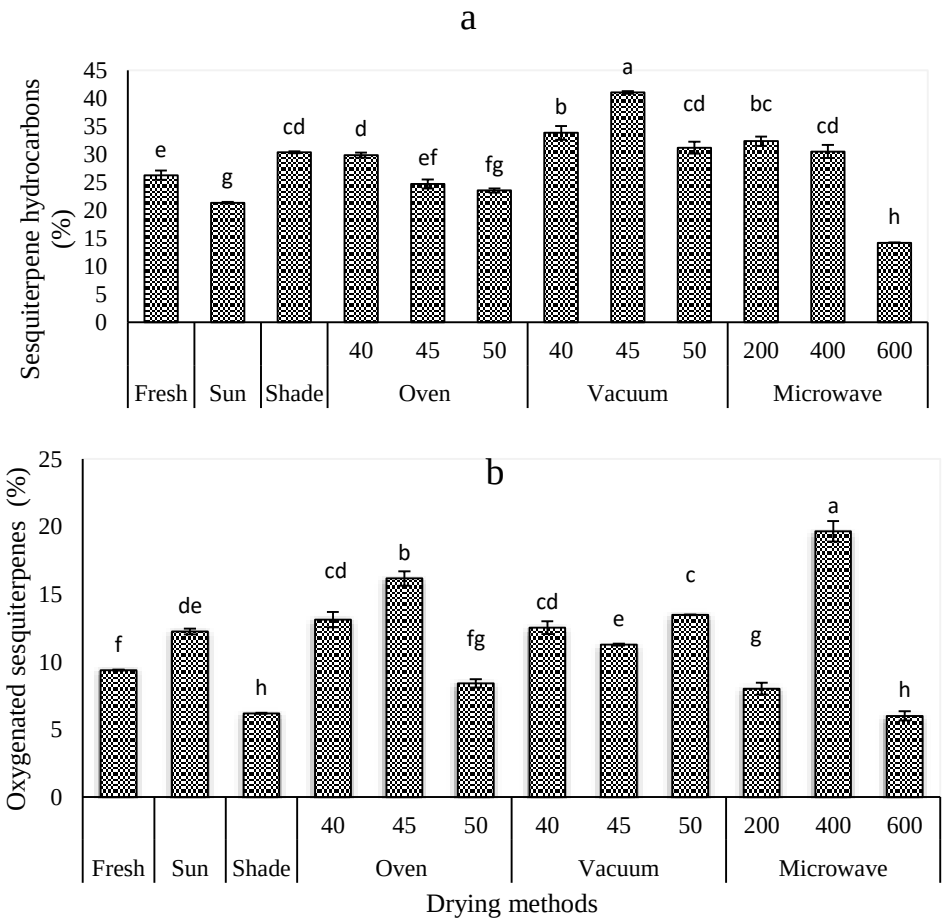

Fig. 3. Sesquiterpenes hydrocarbons (a) and oxygenated sesquiterpenes (b) of essential oil for water mint plants under different drying methods.

Fatty acid (FA) profile

The FA profile showed that caprylic acid (C8:0) ranged from 8.9% in samples dried with microwave 600 W to 18.5% in shade-dried pieces of water mint. The maximum palmitic acid (C16:0) was reported in a vacuum at 40 °C (55.8%), with a 2-fold increase relative to fresh samples. Unlike palmitic acid, steric acid (C18:0) represented the maximum amount in the new plants to be 8.8%. For oleic acid (C18:1), shade drying was optimum, and the results showed decreasing trends in oleic acid by enhancing the temperature in the oven and vacuum. Unlike oleic acid, linoleic acid (C18:2) revealed an increasing trend when the enhanced temperature. The samples dried upon microwave showed higher linolenic acid (C18:3) than other drying methods. Arachidonic acid (C20:4, n-6) ranged from 0.3% in vacuum 50°C to 5.3% in microwave 600 W. The higher saturated fatty acids (SFAs) were obtained in vacuum 40. In comparison, the polyunsaturated fatty acids (PUFAs) in the microwave drying method, especially at 600 W, were higher than other drying techniques (Table 3).

Table 3. Fatty acid profile water mint plants under different drying methods.

Drying method	Palmitic	Stearic	Oleic	Linoleic	Linolenic	Docosahexaenoic	Arachidonic
Fresh	26.7±1.05de	8.83±0.89a	13.4±0.92b	14.1±0.9c	13.1±0.86cd	2.03±1.12b-e	7.6±0.8b
Sun	35.3±2.20c	5.66±0.56b	2.53±0.77g	14.4±0.5c	16.73±0.4b	4.06±1.92ab	7.2±0.4b
Shade	25.06±0.6de	4.4±0.2b-d	23.16±4.3a	5.46±0.8fg	11.5±0.3de	3.73±1.87a-c	8.2±0.3ab
Oven 40°C	52.1±3.45b	5.43±0.85bc	8.56±0.91c	5.26±1.4g	10.9±0.33e	2.23±1.62b-e	4.5±0.3c
Oven 45°C	49.9±1.89b	5.4±0.81b-d	7.36±0.5cd	7.2±0.5d-f	12.7±0.4cd	1.6±0.96de	3.8±0.4cd
Oven 50°C	49.2±1.22b	6±1.60b	6.03±0.5c-e	8.63±0.5d	14.1±1.06c	1.73±0.72c-e	3.6±1.06cd
Vacuum 40°C	55.8±3.09a	4.53±0.2b-d	6.6±0.8c-e	6.6±1.4e-g	12.8±1.07cd	0.83±0.32e	1.6±1.07d
Vacuum 45°C	49.5±1.68b	5.36±0.8b-d	4.8±0.7d-g	8.4±1.6de	14.1±1.32c	1.67±1.15c-e	3.9±1.3cd
Vacuum 50°C	52.3±2b	3.87±0.37c-e	3.76±0.5fg	8.9±1.8d	16.5±1.10b	0.31±0.2e	1.8±1.1d
Microwave 200 W	27.8±1.04d	2.76±0.76e	4.6±0.2e-g	20.6±2.01b	19.4±1.41a	3.63±1.05a-d	9.2±1.4ab
Microwave 400 W	25.7±1.9de	3.8±0.45de	4.03±0.2e-g	22.5±1.5a	19.13±0.9a	5.06±1.15a	9.9±0.9a
Microwave 600 W	23.5±1.13e	5.46±1.01bc	3.76±0.4fg	24.1±1.1a	18.46±0.8a	5.3±0.55a	10.3±0.8a

Values are means ± standard error of the mean (SEM) of five replications (n= 5). Different letters in each column show statistically significant differences among treatments at $P \leq 0.05$.

The effect of different drying methods on the fatty acid composition of *Mentha aquatica* L. showed that the type and amount of these compounds are strongly affected by the drying conditions. By increasing the drying speed (200 W microwaves), the amount of octanoic acid decreased significantly, while in the shade drying method its amount was the highest. Palmitic acid increased at 45 degrees but decreased in the microwave and shade. Stearic acid was almost similar in the shade and oven methods but decreased in the microwave. Oleic acid was affected by the drying speed and increased significantly in the microwave, and was also higher in the shade than in the oven. Linoleic acid (omega-6) increased in the microwave but decreased in the oven. Linolenic acid (omega-3) was higher in the oven than in the shade. But it had the lowest amount in the microwave. Eicosatetraenoic acid showed the highest amount in the dry shade method. Docosahexanoic acid was higher in microwave than oven but was highest in shade.

In general, the amount of saturated fatty acids was highest in oven drying at 45 degrees. The amount of unsaturated fatty acids was reported to be higher in microwave drying at 200 watts than in other methods. Increasing the drying speed increased unsaturated fatty acids and temperature (oven 45 degrees) increased saturated fatty acids in plant tissue (Table 4).

Table 4. Amount and type of fatty acids in *Mentha aquatica* L. under different drying methods.

Saturation	Common Name	Chemical Formula	Shade Drying	Oven 45 °C	Microwave 200 W
Saturated	Octanoic acid	C8: 0	18.154	10.713	2.553
	Palmitic acid	C16: 0	24.966	52.177	16.924
	Stearic acid	C18: 0	4.439	4.519	1.995
Unsaturated	Oleic acid	C18: 1(n-9) C	8.228	3.784	25.411
	Linoleic acid (Omega-6)	C18: 2(n-6) C	10.983	6.480	42.390
	Linolenic acid (Omega-3)	C18: 3 n3	18.706	20.860	7.618
	Eicosatetraenoic acid	C20: 4 n6 ARA	12.600	1.467	2.611
	Arachidonic acid	C20: 5 n3 EPA	0.000	0.000	0.000
	Docosahexaenoic acid	C22: 6 n3 DHA	1.924	0.000	0.499
	Saturated	-	47.560	67.409	21.471
	Unsaturated	-	52.440	32.591	78.529

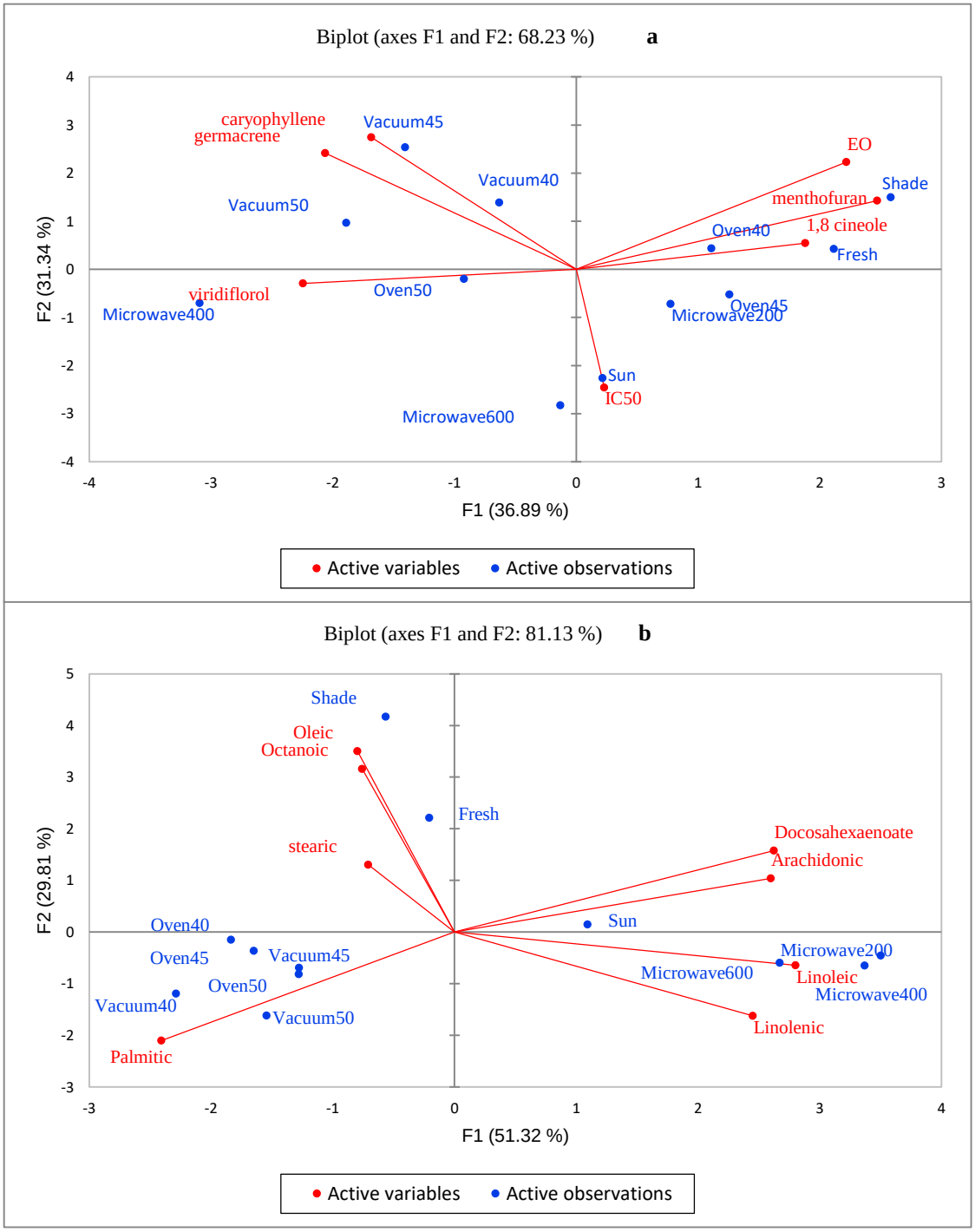

Fig. 4. Principal component analysis for main essential oil composition (a) and fatty acid profile (b) of water mint plants.

Multivariate analysis

The PCA of antioxidant capacity and EO represented that F1 justified EO content, 1,8 cineole, menthofuran, and viridiflorol of traits and fresh, shade, oven 40 °C, oven 50 °C, vacuum 50 °C, and microwave 400 W of drying methods. On the other hand, F2 described IC50, trans-caryophyllene, and germacrene D of treats and vacuum 40 °C, vacuum 45°C, and microwave 600 W of drying techniques (Fig. 4a). PCA of the FA profile showed that F1 justified palmitic, linolenic, linoleic, arachidonic, and docosahexaenoic acids of traits. It did

oven 40 °C, oven 45 °C, oven 50 °C, and all vacuum and microwave treatments. At the same time, F2 explained octanoic and oleic acids of variables and fresh, shade, and vacuum 50 °C of drying methods (Fig. 4b). The agglomerative hierarchy clustering (AHC) results represented four clusters based on the EO profile with a fresh oven at 45 °C. All microwaves in cluster 1, sun drying in cluster 2, shade, oven 40 °C, oven 50 °C, vacuum 40 °C, vacuum 45 °C in cluster 3, and vacuum 50 °C in cluster 4 (Fig. 5a). Moreover, for the FA profile determined, three collections as fresh and shaded were positioned in cluster 1, sun and all microwaves were specified in cluster 2, and all treatments of oven and vacuum were placed in cluster 3 (Fig. 5b).

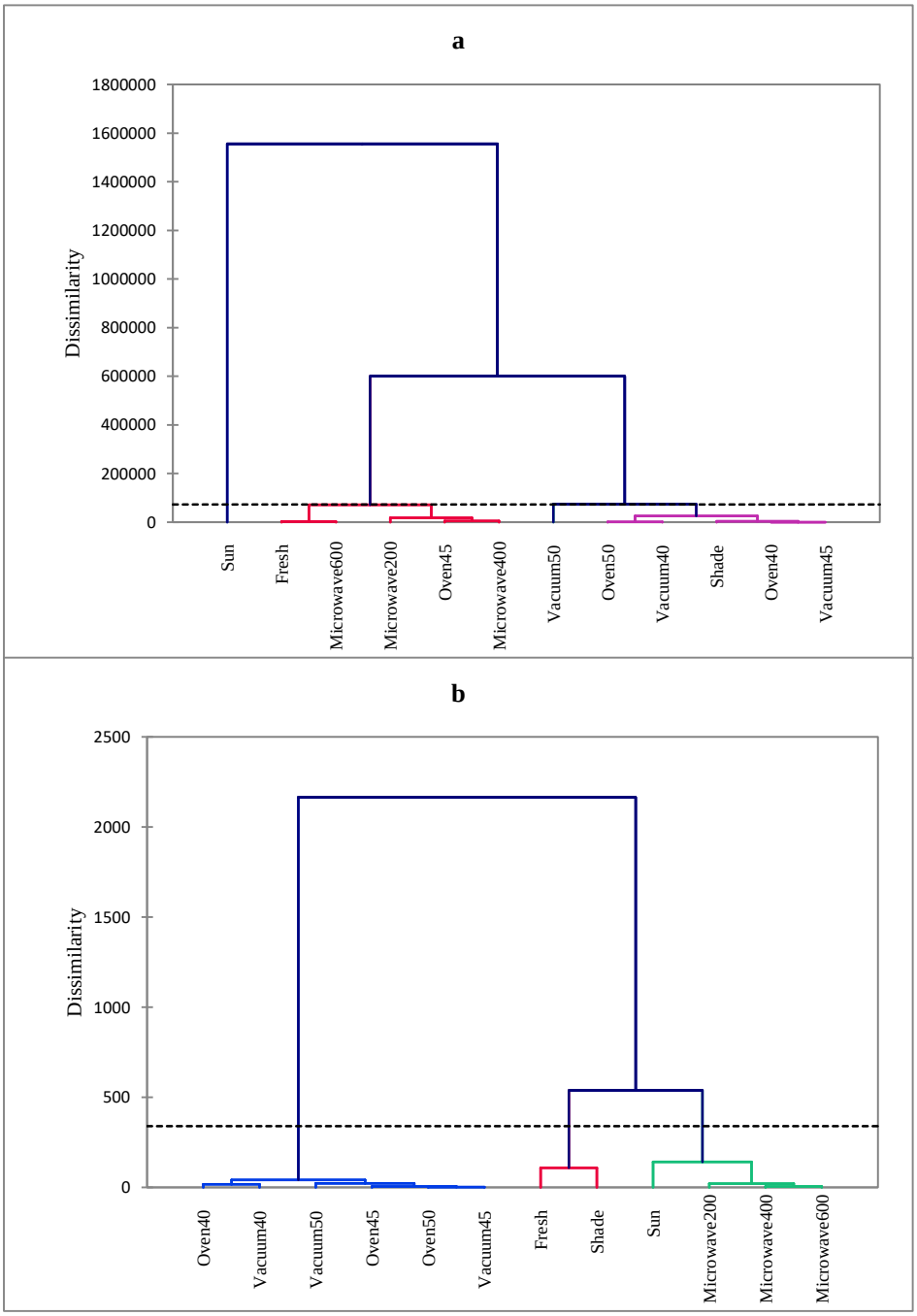

Fig. 5. Agglomerative hierarchy clustering for main essential oil composition (a) fatty acid profile (b) of water mint plants.

DISCUSSION

Drying is the appropriate strategy to reach the optimum quality and quantity of plant ingredients by removing the water. The drying temperature is essential in changing medicinal plants' phytochemicals and antioxidant capacity. According to the results, IC50 in sun-dried samples was higher than in other methods, which showed the minimum antioxidant power due to the adverse effect of sun rays on antioxidant systems in plants. However, the shade and oven at 40 °C and vacuum at 45-50 °C had higher antioxidant capacity relative to fresh samples, which may be a result of the decline in moisture content and enhancement in dry matter amount, and also the inactivation of polyphenol oxidase (PPO) enzyme during the drying process (Ghafoor et al., 2020). The best drying method for plants concerning antioxidant activity was a shade-dried process. In this drying practice, the plant samples were dried in a room with good ventilation and low humidity of 22–27% and without direct sunlight exposure (Ebadi et al., 2015). It is well documented that the shade-drying process, due to its advantages to preserve light-sensitive substances and minimize light-induced chemical reactions such as oxidation, is relatively better than traditional practices such as sun drying (Thamkaew et al., 2021). Similarly, Ozdemir et al. (2018) represented that the minimum antioxidant activity of *Origanum vulgare* L. and *Origanum onites* L. was obtained in fresh and sun-dried samples, while shade drying showed the maximum value.

The EO content in shade drying represented more than other drying techniques. However, sun-exposed plants meant a lower EO content, which was previously reported by Xing et al. (2017), who wrote a higher EO content for shade and oven at 50 °C. It is documented that the collapse of epithelial cells, which released intracellular chemicals, is the reason for the large EO yield. The amount of EOs produced is influenced by several factors, including temperature, drying time, the oil's chemical structure, plant location, and secretory organs. Saeidi et al. (2016) represented that EO content was significantly reduced when the temperature rose from 40 to 80 °C. Volatile oils are reduced considerably when samples are exposed to higher temperatures (oven 80 °C) and direct sunshine, mainly when the essential oil glands are located externally in the leaf. Drying methods can change the density and size of EO glands in leaves, which affects EO production (Soodmand-Moghaddam et al., 2019). The AHC results showed differences among drying methods concerning the EO profile. Therefore, it indicates the significant difference among drying techniques on EO profile, which is noticeably beneficial for the food and drug industries.

Drying techniques had different effects on the EO composition of water mint leaves. The better effect of shade-based drying to conserve the main ingredients of plant materials has been reported in various studies compared to other traditional and new methods (Thamkaew et al., 2021). Good retention of bioactive compounds was reported by shade drying (Ebadi et al., 2015). In drying, temperature, air relative humidity, and airflow are three critical parameters. In contrast to higher molecular weight molecules like sesquiterpenes, lower molecular weight substances like monoterpenes are more volatile and can therefore be easily separated from plant material. Xing et al. (2017) represented that larger molecules, like sesquiterpene hydrocarbons, were released to a greater extent after drying, but smaller molecules, like monoterpene hydrocarbons and oxygenated monoterpenes, were better maintained (Chua et al., 2019).

The results showed that different drying methods of *Mentha aquatica* L. had a significant effect on its beneficial compounds. Drying in the shade and at moderate temperatures resulted in the highest production of essential oils and the highest antioxidant capacity, while drying under direct sunlight showed the lowest efficiency, probably due to prolonged exposure to heat and oxygen, which destroys vitamins and sensitive compounds as well as the activity of residual enzymes. Also, rapid drying with microwave or oven drying at low temperatures

increased the content of unsaturated fatty acids, including oleic and linoleic acids, while oven drying at higher temperatures increased saturated fatty acids, such as palmitic acid. Therefore, to preserve essential oils and antioxidant activity, the use of shade drying is recommended, and to increase unsaturated fatty acids and beneficial heart and brain compounds, the use of an oven or microwave at low temperatures is appropriate, while sun drying is not recommended for nutritional and medicinal purposes.

Fatty acids are essential to human life from a nutritional perspective. In particular, USFAs play a crucial role in maintaining human health since they lower cholesterol levels and guard against diabetes, atherosclerosis, cancer, and heart disease (Wang et al., 2020). The results showed increased PUFAs when plant leaves were dried under oven and vacuum drying temperatures, especially sun-dried samples. This indicates that exposure to sunlight and higher temperatures create stressful circumstances for plant tissues, which results in an increase in PUFAs and a decrease in MUFAs. Wang et al. (Wang et al., 2020) reported the changes in the FA profile upon drying methods, where the temperature had a significant role in the oxidation of FA compounds.

CONCLUSION

The current study showed that drying in the shade and moderate temperatures of the oven produced the essential oils and had the most antioxidant potential, which can be advantageous to human health and the economy. Regarding fatty acid profiles, using a microwave or oven at a low temperature causes a rise in oleic acid, which is beneficial for the heart, metabolism, and mental health. It is advised to refrain from using the drying procedure on sun-exposed samples because they have the lowest antioxidant yield and capacity. To sum up, after recommending shade conditions, we can utilize the oven's low temperature and vacuum.

The present study was limited to examining drying methods under laboratory conditions, and the stability of the compounds during long-term storage was not evaluated. Therefore, future research is recommended to investigate industrial-scale applications and the stability of these compounds during extended storage periods.

Conflict of interest

The authors declare that there is no conflict of interest.

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