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Investigation of the Efficiency of Drying Conditions for Essential Oil Production from Aromatic Plants

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Abstract

The active components of aromatic medicinal plants have extensive applications in many disciplines. These essential oil components are extracted from medicinal plants, and the removal of water is a critical step of this process. Different drying methods have been developed to produce high-quality and high-quantity products. In this study, different drying methods were investigated with respect to their effects on herbal oil content. Two distinct aromatic plants, i.e., *Thymus vulgaris* L. and *Mentha citrata* Ehrh., were selected for physical and chemical analyses. To understand and elucidate the importance of method selection, the relationship between parameters, such as moisture content and drying time, was correlated with essential oil recovery and active ingredient levels. Recently, solar tunnel drying emerged as a novel technique with various advantages. We implemented this technique to analyze its effectiveness on the removal of water from different plant species. Our recent findings from essential oil and humidity content analyses showed that *T. vulgaris* L. is a more suitable candidate for the solar tunnel drying process than *M. citrata* Ehrh. Solar tunnel and oven drying have been determined to be the best dehumidification methods for both plant species. The differences between these drying methods were not significant for *M. citrata* Ehrh. By contrast, these drying methods can cause significant variations in the oil content of *T. vulgaris* L. Essential oil compositions have also been observed to be dependent on the drying conditions. These results indicated the significance of method selection in obtaining products with high yield.

Keywords: active components, chemical composition, drying method, medicinal plant

Introduction

Aromatic and medicinal plants have been regularly used as the ingredients of medicines, foods, and cosmetics since the beginning of history. The essential oils and other chemical constituents of these plants are exploited for industrial purposes as active ingredients or for their aroma [1, 2]. In addition to its extensive applications in different industries, essential oils have been used as important pharmacological agents, and the antibacterial, antiviral, health protective, and anticarcinogenic effects of essential oils have all been previously reported [3-5]. Given their diversity and multifunctional features, aromatic medicinal plants are considered to be essential natural assets with a significant value. Apart from their aromatic properties, such as taste and smell, their active chemical constituents make these plants remarkably useful for the manufacture of various additives.

Thymus vulgaris L. and *Mentha citrata* Ehrh. belong to the family Lamiaceae, and their essential oils are critical components in a number of raw materials used in the pharmaceutical, food, and cosmetics industries. *T. vulgaris* L., or thyme, is a perennial plant of the Mediterranean region that has been used as a spice, home remedy for digestive problems, drug, perfume, cosmetic, and insecticide for centuries [3]. Extracts of this plant have antimicrobial and anti-inflammatory applications and do not exhibit genotoxicity or cytotoxicity [4]. In thyme oil, thymol and carvacrol are normally the major and minor phenolic compounds, respectively [6, 7], and linalool and *p*-cymene are the major nonphenolic components [8]. *M. citrata* Ehrh., which is also known as bergamot mint, is commercially cultivated in Italy and the United States of America, and its leaves are widely consumed in Mexico and Cuba as herbal tea or spice. The essential oil of bergamot mint has a strong lavender odor that arises from its primary components, i.e., linalyl acetate and linalool [9]. *M. citrata* Ehrh. oil contains approximately 50 different essential oils, and the oil extract of this plant is mostly composed of linalyl acetate, linalool, and eucalyptol [9]. These plants were selected on the basis of their physiological differences. *M. citrata* Ehrh. is a leafy plant and has wider leaves than *T. vulgaris* L. Hence, these plants with different water-holding capacities were selected as model plants.

As mentioned previously, essential oils from aromatic medicinal plants are an important part of the pharmaceutical, cosmetic, perfumery, and food markets. In addition to its benefits, the components extracted from natural sources are considered to be more bioavailable than synthetically produced components because of the remaining side products after chemical synthesis. However, the use of these medicinal species in diverse industries has resulted in increased demand for high-quality raw materials. The major challenge to the production of large quantities of quality essential oils is the intense labor requirement. Energy-efficient techniques, e.g., using solar panels, have emerged as a promising solution for maximizing essential oil yield while minimizing energy consumption and cost [10].

Moisture content is a significant parameter in defining the chemical and physical features of aromatic medicinal plants. The removal of water is an essential process for inhibiting enzymatic and microbial activities to extend shelf life [11]. Therefore, following postharvest operations, plants should be dried using an adequate method that reduces humidity without affecting the quality of active components. In general, the quality of an essential oil is defined by several parameters, such as level of active substances, color, and aroma. Hence, the drying method should be selected after considering the desired composition of the final product. Chemical additives should be avoided during drying. Therefore, natural drying methods are preferred. The moisture in the final product must be at an equilibrium level with the local climate, and the total microbial counts must be less than the designated limits.

High essential oil content and enrichment of the characteristic components (the main or key content of an industrial product with high profit) of these plants are desired by all industries. Oil content is affected not only by agricultural practices but also by postharvest operation. Controlled drying immediately after harvesting reduces essential oil losses and conserves the characteristic components, whereas delays in drying and high humidity decrease productivity.

The effects of different drying methods on the active ingredients of essentials oils have been investigated. The simplest dehumidification method is natural drying, in which herbs can be dried under direct sunlight or shade. Given the high investment cost for artificially drying medicinal plants, sun drying is one of the most popular drying methods, particularly in the Mediterranean region where sunshine is abundant. Meanwhile, shade drying is used when exposure to direct sunlight may affect active ingredient levels.

However, conventional drying methods have many disadvantages, including crop losses from heavy rains or storms, microbial infection, mold development, low product quality as a result of animal/insect residue, and dust contamination [12]. Intense solar radiation reduces the quality of essential oils (both in content and color). Therefore, drying ovens and solar panels have been developed to improve the quality and quantity of essential oils [13]. However, each aromatic medicinal plant requires a different treatment, and the selection of the most appropriate method plays an important role in maximizing yield and quality. For example, sun-exposure-based methods are preferable for essential oils that contain photoactive materials.

Given that harvested medicinal plants usually have a moisture content of 80% and are stored at 11%, drying of these crops requires an energy equivalent of 1 to 2 L of fuel oil to produce 1 kg of crude oil. A solar cabinet dryer that has low investment cost and operational expenses, is easy use, is resistant to bad weather, dries rapidly, and produces good quality products with respect to certain factors, such as color and taste [14], may be useful to farmers for drying plant materials, particularly in Mediterranean countries where sunshine is abundant.

Method selection is also important for specific component extraction. Thus far, different extraction methods or techniques (e.g., plant embedding) have been investigated and compared to achieve better essential oil yield [7, 11]. For instance, hydrodistillation has been observed to be more applicable for active component isolation from *M. citrata* than steam distillation. Method optimization has a significant influence on active component yield.

The objective of the present study was to determine the effect of different drying methods on the essential oil content and composition of *T. vulgaris* L. and *M. citrata* Ehrh. grown in Cukurova, Turkey.

Materials and Methods

Plant material and drying process. The aboveground parts of *T. vulgaris* and *M. citrata* were used in this study. The plants were grown in an experimental area of the Cukurova University Agricultural Faculty in Adana (southern Turkey). For the drying experiments, each plant type was harvested in its development stage to ensure the optimal active component content and dried immediately. To analyze the effects of different drying methods on the essential oil content and composition of *T. vulgaris* and *M. citrata*, conventional drying methods, i.e., sun and shade drying, were compared with solar tunnel and cabinet drying at 40 °C, which was used as the control. Plant materials were spread out for drying and given that these drying methods are dependent on the weather, the drying temperature fluctuated over the course of the study. Drying was stopped as soon as the herbs reached the appropriate dehumidification level. Drying under constant conditions in an electrically heated laboratory drying oven at 40 °C for 12 h served as the control. This drying time has been proven to be suitable in preliminary experiments to achieve the desired final moisture content of 10% ± 2.5%.

Sun drying. Sun drying took place on the ground, and the plant material was placed approximately 5 cm from the ground on a lattice net bordered by a frame. This corresponds to a load of 0.5 kg/m^2. The material to be dried was manually mixed and turned regularly during drying.

Shade drying. Shade drying took place in a 65 cm × 55 cm hall with panels. The hurdles consisted of wooden frames covered with fly screens. The shelves were placed on top of each other at a distance of approximately 25 cm by means of a rack. The material to be dried was placed such that the layer thickness was approximately 5 cm (approximately 0.5 kg/m^2). The hall was ventilated through open windows.

Solar tunnel drying. Solar tunnel drying took place in a solar tunnel dryer developed at the University of Hohenheim [14] (Figure 1). The material to be dried was placed on grates in the drying tunnel at a layer thickness of approximately 5 cm, and air heated in the solar collector flowed horizontally across it. The fans were directly coupled to a photovoltaic module with 50 W.

Measurement of the drying conditions. During the drying tests, the temperatures of ambient air and drying air, as well as the global radiation, were measured continuously and recorded at intervals of 5 min. Temperature

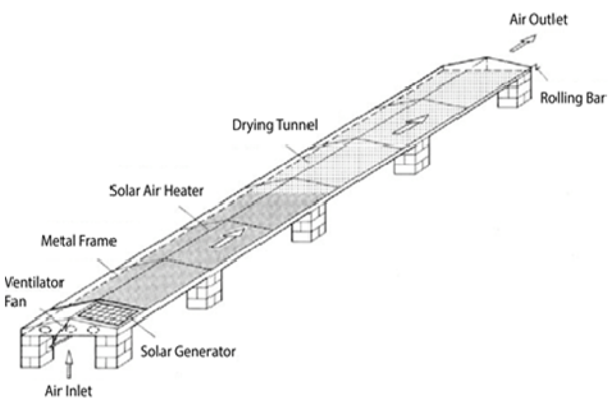


Figure 1. Solar Tunnel Dryer at the University of Hohenheim

was measured using a thermocouple, and global radiation was measured using a pyranometer. The ambient humidity data were obtained from the campus weather station records at Cukurova University.

Quality analysis. The determination of moisture and essential oil contents was conducted before and after the drying process. Moisture content was determined gravimetrically using the drying furnace method (3 h at 105 °C) and compared with the total mass. The final moisture content of each experimental group was approximately 8% to 10%. The moisture ratio should be decreased to 10%, which is the critical limit for storage. The determination of essential oil content was conducted using a Neo Clevenger steam distillation apparatus, with 20 g dried material and 2 h distillation time, following the method recommended by the European Pharmacopoeia. The compositions of the essential oils were assessed by means of solid-phase microextraction in combination with gas chromatography (GC)/mass spectrometry. In this method, the essential oil components were obtained from rehydrated aromatic plants and absorbed on 100 m Polydimethylsiloxane -coated fiber. Then, 0.1 g drug + 0.4 mL NaCl (10%) were added.

Statistical evaluation. Statistical analyses were conducted using Microcomputer Statistics written in C programming language statistical software. The results of the investigated *T. vulgaris* L. and *M. citrata* herbs were evaluated separately. A least significant difference test was used to test for differences, and a p value of <0.05 was considered significant [15].

Results and Discussion

Two different plant species were used in this study to investigate the efficiency of different drying methods. *M. citrata* has wider leaves than *T. vulgaris*. These two aromatic plants are preferred candidates with comparable water content. Four different methods, i.e., sun, shade, solar tunnel, and oven drying, were used to dehydrate the herbs. Oven drying was considered the control because this technique provides constant experimental conditions and is independent of the weather. Oven drying eliminates temperature fluctuations. Thus, the samples can be dried under constant conditions. Photo/heat fluctuation labile active component can be effectively isolated by this technique [10]. For other techniques, day/night temperature differences and weather conditions are important parameters that may alter the quality of the final product. Ambient temperature and relative humidity of the air are essential factors during shade drying, whereas solar radiation is the major influencing parameter during sun drying because it reaches the upper layers of the drying material and leads to an increase in the actual temperature. In the solar tunnel dryer [11], solar radiation heats the air and powers the fans. Therefore, the amount of solar radiation, the ambient temperature, and the average temperature of drying air in the solar tunnel dryer are shown in Figure 2. The data were recorded from a 2 day drying test at the Adana site.

Solar radiation reached a value of approximately 900 W/m^2 at 03:45 (local time). Ambient temperature reached a high of 31.2 °C at 13:35 (local time) and decreased to 22 °C at 04:45 (local time). Thus, the shade drying ambient temperature was always less than the temperature of the control tray dryer. The air in the solar tunnel dryer was more than 20 °C warmer than the ambient temperature when exposed to full solar radiation. Thus, the maximum drying temperature reached slightly more than 50 °C, which was more than the temperature of the control tray dryer. At night, the temperature in the solar tunnel dryer was less than the ambient temperature because of the heat radiating from the black film.

Given the differences in the use of solar irradiation and the three other processes, the thermal power available for drying was different for the investigated methods; thus, the drying time varied accordingly, with shade > sun > solar. Shade drying required 5 to 8 days to reach a final moisture content of between 8.7% and 12.5%, depending on the type tested. Oven drying was the most rapid method (Table 1). Meanwhile, the performance of the solar tunnel dryer was close to that of the oven drier. The solar dryer was as effective as the oven dryer but had a larger operating capacity and required no energy similar to the natural drying technique.

The major essential oil components were identified using GC analysis, and the effects of different drying methods on active component content were evaluated [7]. The total oil contents and active ingredient levels differed depending on the drying method and plant species. The solar tunnel and oven drying methods produced the highest total oil contents from *T. vulgaris* [5, 6], at 2.60% and 2.70% (of the total oil weight), respectively (Figure 3). Shade and sun drying were significantly different from both artificial methods and each other at 1.40% and 1.10%, respectively.

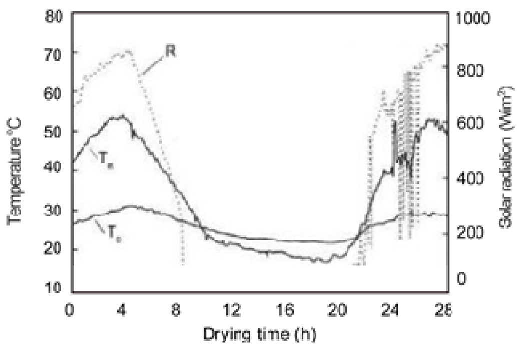
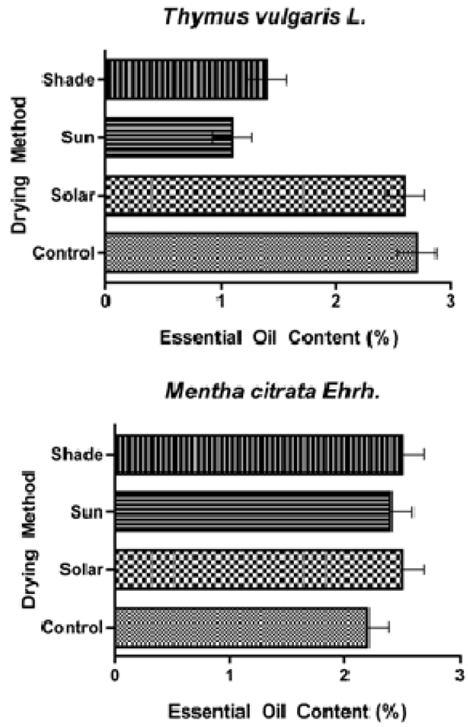


Figure 2. Solar Radiation (*R*), Ambient Temperature (T_0), and Mean Temperature (T_m) of Drying Air in the Solar Tunnel Dryer (Bulk Depth of 5 cm)

Table 1. Drying Time and Final Moisture Content Analyses of *Thymus vulgaris* L. and *Mentha citrata* Ehrh. After Sun, Shade, Solar Tunnel, and Oven Drying

	Thymus vulgaris L.		*Mentha citrata* Ehrh.	
	Drying Time (d)	Final Moisture (MC w. b.)	Drying Time (d)	Final Moisture (MC w. b.)
Shade	5.0	8.70	8.0	12.50
Sun	2.0	9.26	2.0	11.11
Solar	1.0	4.65	1.0	8.00
Oven	0.5	2.82	0.5	4.84

*MC w. b. = moisture content wet basis, d = days



	SHADE	SUN	SOLAR	CONTROL	LSD,5%
Thymus vulgaris L.	1.40	1.10	2.60	2.70	0.17
Mentha citrata Ehrh.	2.20	2.40	2.50	2.80	0.19

Figure 3. Essential Oil Contents (%) of *Thymus vulgaris* L. and *Mentha citrata* Ehrh

With *M. citrata*, shade drying produced a significantly lower oil content of 2.20% than the other types of drying. Meanwhile, the oil contents of sun and solar tunnel drying at 2.40% and 2.50%, respectively, were not significantly different. In the case of *M. citrata*, sun drying produced a similar oil content to solar tunnel drying, indicating that the choice of drying method can be dependent on the plant species (Figure 3). The reason for this result could be the high water content of *M. citrata* because of its wide leaves [8].

The total oil content analyses provided a quantitative comparison of the drying methods, and shade drying was determined to be the least effective technique for both plant species because of the longer drying time required to reach the minimum necessary moisture content. Alternatively, the difference could be attributed to the remaining water content after the drying process, which was higher in the natural methods than in the artificial methods (Table 1). The removal of water is a critical step for the preservation of essential compounds, and the final moisture percentage of *T. vulgaris* was relatively high for sun and shade drying and low for oven and solar tunnel drying. Correspondingly, the essential oil content was significantly high in oven- and solar-tunnel-dried samples. A similar trend was also observed in *M. citrata*, where the moisture contents of solar-tunnel- and sun-dried samples correlated inversely with the oil contents. In addition to the similar sun and solar tunnel drying results of *M. citrata*, the shade drying process for *M. citrata* was longer than that of the other processes, which may have affected the percentage oil content. The comparison of the final moisture content indicated that the drying operation for *M. citrata* is longer than that for *T. vulgaris* (Table 1).

Table 2. Amounts of the Essential Oil (% of the Total Weight) Components of *Thymus vulgaris* L. After Shade, Sun, and Solar Tunnel Drying Compared with Those of the Control

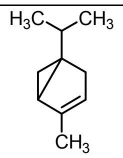
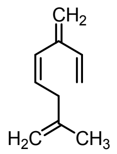
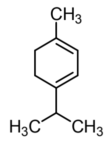
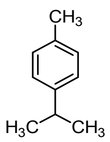
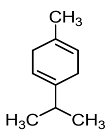
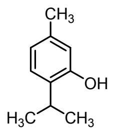
COMPONENT	STRUCTURE	OVEN (%)	SHADE (%)	SUN (%)	SOLAR (%)
α-Thujene		2.18	2.10	3.60	3.20
β-Myrcene		2.28	2.20	4.70	3.10
α-Terpinene		1.88	1.20	3.60	2.20
***p*-Cymene**		55.06	57.20	45.00	54.60
γ-Terpinene		9.14	10.60	23.80	14.70
Thymol		10.50	9.90	4.90	5.30

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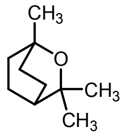
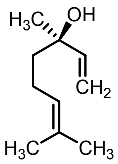
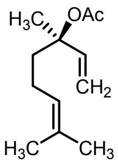
Table 3. Amounts of the Essential Oil (% of the Total Weight) Components of *Mentha citrata Ehrh* After Shade, Sun, and Solar Tunnel Drying Compared with those of the Control

COMPONENT	STRUCTURE	OVEN (%)	SHADE (%)	SUN (%)	SOLAR (%)
1,8-Cineole (Eucalyptol)		28.40	28.10	28.40	25.50
Linalool		32.50	35.50	34.90	35.10
Linalyl acetate		29.8	28.2	27.7	30.90

The major active components of each herbal oil were evaluated by GC analysis (Tables 2 and 3). Notably, the experimental groups exhibited different active ingredient ratios even when they have similar total oil contents. This finding can be attributed to temperature fluctuations during the solar tunnel, sun, and shade drying operations (Figure 2). Meanwhile, oven drying applies constant temperature during the dehumidification process. Some active components could be possibly affected by the temperature fluctuations, whereas other active components could be more resistant to varying temperatures.

Direct sunlight may affect some active compounds, e.g., the thymol content has been observed to be higher after oven drying than after sun drying (Table 2). Conversely, the ratio of terpinene derivatives has been determined to be higher in sun-dried samples than in oven-dried samples. α-Terpinene compounds can be converted into *p*-cymene by solar radiation, and these types of alteration may result in different active ingredient ratios among different groups [4]. The essential oil components of *M. citrata* did not differ significantly. Thus, plant type may also be a factor in the quantity and quality of harvested essential oil (Table 3). *M. citrata* requires a longer drying operation than *T. vulgaris* probably because of its wider leaves and prolonging the drying period might be the reason for the statistically insignificant difference between dehumidification methods.

This comparative analysis is important to understand and develop plant-type-specific techniques. In light of previous and recent studies, this study will be a significant contribution to the database to achieve the ultimate quality with low cost and energy requirements.

Conclusion

Different drying methods were evaluated in this study to understand the critical parameters for producing the highest quantity and quality of essential oils. Solar tunnel drying is an excellent option for dehydration operations with both low energy and cost requirements. This method has been determined to be applicable to the tested species to achieve a high herbal oil yield. However, the success of this method is dependent on the plant species. Moreover, this method appears to be more successful for *T. vulgaris* than *M. citrata*. The dehydration of *M. citrata* requires a longer time than that of *T. vulgaris*, and the final moisture levels for this plant were higher in all methods tested. Therefore, the drying time and remaining moisture content are significant factors in maximizing the product yield. The compositions of the final herbal oils were also investigated, and the dehydration methods have been observed to affect the active component ratios. Fluctuating or constant temperatures, solar radiation, and environmental factors may underlie these differences, and this conclusion presents important cues to obtain high-quality extracts in the future. Method selection has a considerable influence on the quality and production efficiency of the desired active component and this study will be expanded to different plant species that are harvested from different growing regions. This study will serve as a guide for other studies, which will explain the relationship between land types, breeding, and active component isolation to develop new methods to produce high-value materials.

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