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The Change of Drying Time and Quality Parameters of Lemon Balm (*Melissa officinalis* L.) with Different Temperature Profiles of Drying Air

Murat ERTUĞRUL[1], Sefa TARHAN[2*]

[1] Tokat Gaziosmanpasa University, Graduate School of Natural and Applied Sciences, 60250, Tokat, Turkey
[2] Tokat Gaziosmanpasa University, Faculty of Engineering and Natural Sciences,
Mechatronics Engineering Department, 60250, Tokat, Turkey
*corresponding author: sefa.tarhan@gop.edu.tr

Abstract

Lemon balm (*Melissa officinalis* L.), one of commercially important medicinal and aromatic plants, must be dried immediately after harvest because of its high initial moisture content (72.99% to 80.11%, wb). Its quality parameters such as its color and essential oil conditions are very sensitive to drying conditions. The most important factor of drying conditions is the drying air temperature profile. Five different drying air temperature profiles were used to maintain the quality parameters of lemon balm samples while reducing the drying time as much as possible. Drying trials with the constant low temperature (35 °C) and the increasing temperature profile gave the most closest color values of dried samples to the ones of fresh samples. The maximum color changes occurred with the constant high temperature (60 °C) and the triangle temperature profile. The drying trials with the constant low temperature gave the lowest essential oil loss (24.28% loss) while the drying trials with the constant high temperature gave the highest essential oil loss (63.95% loss). The increasing temperature profile in which the drying air temperature increased from 35 °C to 60 °C in 8 hours became the most convenient drying air temperature profile for drying lemon balm when the results obtained in this study were evaluated altogether.

Keywords: Medicinal and Aromatic Plants, Essential Oil Content, Color Change, Convective Hot Air Drying.

Melisa Bitkisinin (*Melissa officinalis* L.) Kurutma Süresi ve Kalite Parametrelerinin Kurutma Havası Sıcaklık Profili ile Değişimi

Özet

Yüksek ilk nem içeriği (%72.99 ila %80.11, yb) nedeniyle, önemli ticari değere sahip tıbbi ve aromatik bitkilerden olan melisa bitkisi (*Melissa officinalis* L.) hasattan hemen sonra kurutulmalıdır. Renk ve uçucu yağ içeriği gibi kalite parametreleri kurutma koşullarına çok duyarlıdır. Kurutma havası sıcaklığı profili kurutma koşullarını etkileyen en önemli faktördür. Melisa bitkisinin kalite parametrelerini korumak ve kurutma süresini oldukça azaltmak için beş farklı kurutma havası sıcaklığı profili kullanılmıştır. Sabit düşük sıcaklık (35 °C) veya artan sıcaklık profili ile kurutma denemeleri, taze örneklere en yakın renk değerlerini vermiştir. Sabit yüksek sıcaklık (60 °C) ve üçgen sıcaklık profilleri ise maksimum renk değişimlerine neden olmuşlardır. Sabit düşük sıcaklıktaki kurutma denemeleri, en düşük uçucu yağ kaybına (%24.28 kayıp) neden olurken, sabit yüksek sıcaklıktaki kurutma deneyleri, en yüksek uçucu yağ kaybına (%63.95 kayıp) neden olmuştur. Bu çalışmada elde edilen sonuçlar birlikte değerlendirildiğinde, kurutma hava sıcaklığının 8 saatte 35 °C'den 60 °C'ye yükseltildiği artan sıcaklık profili, melisa bitkisinin kurutulması için en uygun kurutma havası sıcaklık profili olmuştur.

Anahtar Kelimeler : Tıbbi ve Aromatik Bitkiler, Uçucu Yağ İçeriği, Renk Değişimi, Konvektif Sıcak Havalı Kurutma

1. Introduction

Lemon balm (*Melisa officinalis* L.) is a medicinal and aromatic plant with a high economic value because it is commercially used for different purposes due to its essential oil content. Lemon balm plant is used as herbal tea because of its calming effect and pleasant smell. Essential oils obtained from the Lemon balm plant contain antibacterial, antiviral and antiseptic effects [1-4]. Growing stage (pre-florescence, florescence and post-florescence) of lemon balm affects the dry herbal yield (4721.4-9293.0 kg·ha^{-1}) and essential oil content (0.23-0.45 mL·100 g dry matter^{-1}) of lemon. The dry herbal yields and essential oil contents of lemon balm reached their maximum values at its florescence stage. The main components of lemon balm essential oil are E-citral (25.90-36.76%), Z-citral (17.91-26.86%), caryophyllene oxide (10.65-20.11%) and citronellal (0.58-11.78%). The pre-florescence favored partially Z-citral and E-citral contents. Overall, the florescence stage is the recommended harvest time for the commercial production of lemon balm [2].

Most medicinal and aromatic plants must be dried immediately after harvest since they are exposed to chemical and microbiological degradations. Drying is the postharvest operation of removing the excessive moisture from newly harvested plants. Drying methods and conditions affect drying time and quality parameters of medicinal and aromatic plants [4-13]. The most common method of drying medicinal and aromatic plants is convective air drying. In convective air drying, ambient air or heated air is forced through drying plants and the air gains moisture from drying materials. Different drying methods were used to find the appropriate drying method and conditions for aerial parts of coriander. They were sun drying (exposing directly with sunlight), shade drying (under shadow) oven drying (40 and 60 °C), microwave drying (500 and 700 W) and freeze drying. The freeze-drying resulted in the highest essential oil content (0.18 mL·100 g dry matter^{-1}) while the shade drying gave the second best essential oil content (0.18 mL·100 g dry matter^{-1}). Oven drying at 40 °C resulted in the essential yield similar to the one of fresh sample. Oven drying at 60 °C and microwave drying reduced the essential oil content dramatically [5]. Even though freeze-drying and shadow drying seem to be the best drying methods for aerial parts of coriander in terms of their preservation capacity of essential oil contents, they are normally expensive and/or time consuming drying processes. For practical purposes, oven drying at 40 °C can be the plausible choice. *Acorus calamus* L. rhizomes were dried by sun drying, shade drying and oven drying (40 °C for 60 h and 70 °C for 24 h). Increase of drying temperature from 40 to 70 °C decreased the essential oil content from 2.40 to 1.98 (mL·100 g dry matter^{-1}) [6]. In addition, oven drying at 40 °C decreased β-asarone content compared to the other drying methods. The literature shows that the most determinant factor of convective air drying is the temperature of drying air. The increase of drying air decreases drying time of medicinal and aromatic plants but worsens the product quality by decreasing essential oil content and changing the original plant color.

Non-constant drying air temperature during the drying process may relieve the adverse effects of high drying air temperature while still shortening the drying time [4, 10-12]. In this case, the appropriate profile of non-constant drying air temperature during the drying process should be determined for each medicinal and aromatic plants since they have different morphological properties. Newly harvested fresh peppermint samples were dried by using different drying air temperature profiles (Constant 35 °C, Constant 55 °C, Incremental rise from 35 to 55 °C in 4 hours and Incremental rise from 35 to 55 °C in 8 hours) to retain their original color and essential oil contents. The temperature profile in which drying air temperature gradually increased from 35 to 55 °C in 4 hours and stayed constant 55 °C after 4 hours were recommended as the best temperature profile. It reduced the drying time from 18.5 h to 10.0 h compared to the constant 35 °C profile while retaining the essential oil content (2.487 mL·100 g dry matter^{-1}) close to the fresh peppermint plants (2.615 mL·100 g dry matter^{-1}) [12]. The drying air temperature value of lemon balm were increased from 40 °C to 50 °C at different moisture content values of lemon balm during drying (20%, 30%, 40% and 50%). The change of drying temperature from 40 to 50 °C at 50% moisture content decreased the essential oil content from 0.17 to 0.06 mL·100 g dry matter^{-1}. However, the change of drying temperature from 40 to 50 °C at 20% moisture content retained the original color and essential oil content while reducing the drying time by 27% and energy consumption by 11% compared to the standard drying at constant 40 °C [4]. The aim of this study was to find the appropriate drying air temperature profile which could shorten the drying time compared to those of the low (≤ 35 °C) constant drying air temperatures while retaining the color and essential oil content of lemon balm (*Melissa officinalis*, L.) plants.

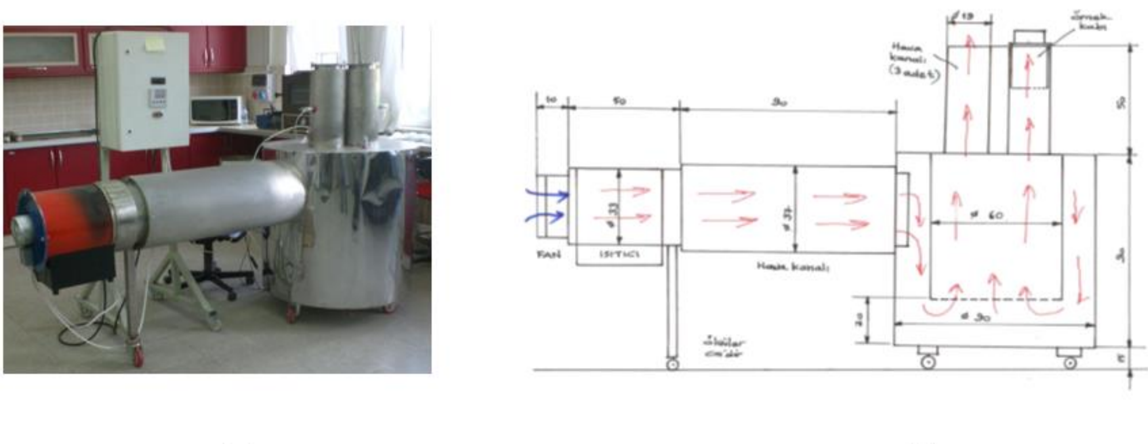
2. Materials and Methods

2.1. Drying Material

Lemon balm (*Melissa officinalis* L.) plants were cultivated in a field of ~ 24 m^2 in the experimentation area of Tokat Gaziosmanpasa University Directorate of Agricultural Research and Application Centre, Tokat, Turkey. The plants were regularly irrigated, fertilized and weeded until their harvest at was harvested during the flowering period. The harvested plants were immediately chopped to 10 cm long pieces and their stems and leaves were not separated.

2.2. Laboratory-Type Convective Dryer

Laboratory type convective dryer used the ambient air sucked by its fan and heated by its electrical heater based on the selected drying air temperature profile (Figure 1). The fan and electrical heater were operated with the control panel. The heated air was forced through the main chamber to the drying chimney. The main chamber had two cylindrical containers mounted concentrically to mix and send the heated air to the drying chamber uniformly. Before each drying trial, 250 g chopped lemon balm samples were filled into three sample containers and then each sample container was placed into one of three drying chimneys. The sample containers having perforated bottom let the hot air coming from the main chamber trough the drying plant samples. The samples containers were taken from the drying chimney and their weights were immediately determined with a laboratory balance (AND GF-3000) and placed back into the drying chimney. A sample container was taken out from a drying chimney for weight measurement was putted back into a different drying chimney to reduce the effect of the uncontrolled heterogeneity in drying air. The completion of each drying trial was attempted at the final moisture content of 10% (wb).



(a) (b)

Figure 1. Laboratory type convective dryer (a: General view; b: Schematic view)

2.3. Temperature Profiles of Drying Air

Five different drying air temperature profiles were selected for this study as given in Table 1. The first two profiles had the constant temperatures (35 and 60 °C) to observe the effect of high drying air temperature on the final quality of dried lemon balm plants. The other three drying air temperature profiles had non-constant drying air temperature profiles.

Table 1. Drying air temperature profiles used for drying trials.

Profile Code	Temperature Profile	Explanation
P1	Low Constant 35 °C	The temperature stayed constant at 35 °C
P2	High Constant 60 °C	The temperature stayed constant at 60 °C
P3	Triangular temperature	The temperature gradually increased from 35 °C to 60 °C in 30 minutes and gradually decreased back to 35 °C in 30 minutes. This triangular pattern was repeated until the end of drying trial.
P4	Increasing temperature	The temperature gradually increased from 35 °C to 60 °C within 8 hours. After 8 hours, it stayed constant at 60 °C.
P5	Decreasing Temperature	The temperature gradually decreased from 60 °C to 35 °C within 8 hours. After 8 hours, it stayed constant at 35 °C.

2.4. Color Analysis

Minolta (CR-400) Color Meter (Chromameter) was used to determine three color values (L*, a* and b*) of fresh and dried samples of lemon balm plants. L* gave the brightness value from 0 to 100. a* gave the value of redness/greenness. Positive value represented redness, while negative value a represented green. b* gave the value of yellowness/blueness. Positive b values represented yellowness, while negative b* values represented blueness. Values 0 of a* and 0 of b* represented colorlessness [14]. Ten readings were taken from each fresh or dried sample.

2.5. Essential Oil Extraction

Neo Clevenger apparatus was used to determine the total essential oil contents of fresh and dried samples of lemon balm plants. Each extraction longed for 2 hours. 350 g fresh samples and 50 g dried samples were taken for each extraction process. The volume of the extracted essential oil was measured and it was poured into a storage container and stored in the refrigerator at 4 °C. The amount of essential oil content was expressed in “ml per 100 g dry substance”.

2.6. Statistical Analysis

The effects of different drying air temperature profiles on drying time, essential oil ratio and color components (L*, a* and b*) were statistically evaluated based on Variance Analysis and Duncan multiple comparison test. SPSS program was used for statistical analysis. p-values less than or equal to 0.05 ($p \leq 0.05$) indicates that mean values are statistically different from each other based on Duncan test results.

3. Results and Discussion

The moisture contents of fresh lemon balm samples ranged from 72.99% to 80.01% (wb) (Table 2). It changed from harvest to harvest probably because of uncontrolled variations in climatic and agronomic conditions such being irrigated or not irrigated close to harvest. The variation among the moisture contents of fresh samples affected the final moisture contents of dried samples even though the completion of each drying trial was attempted at the final moisture contents of 10% (wb). Therefore, the final moisture contents of dried samples were different than the attempted final moisture content and changed from 4.82% to 17.34% (wb).

Table 2. Moisture contents of fresh and dried samples of lemon balm plant (% wb)

Temperature Profile	Fresh Samples			Dried Samples		
	Replications			Replications		
	I	II	III	I	II	III
P1	80.01	73.99	73.99	15.79	15.23	16.51
P2	80.01	73.99	73.99	4.84	5.99	12.22
P3	73.99	75.98	72.99	6.45	5.88	9.19
P4	73.99	75.98	72.99	4.82	17.34	10.58
P5	73.99	75.98	72.99	6.85	13.89	11.29

The drying air temperature profiles affected the drying time of lemon balm drastically as seen in Table 3. The high constant temperature profile (P2) shortened the drying time to almost one sixth of the low constant temperature profile (P1). The decreasing temperature profile (P5) also gave a very similar result to the high constant temperature profile because it initially started at 60 °C and slowly decreased. It was reported that the increase of drying air temperature had decreased the drying time of medicinal aromatic plants exponentially [13]. The triangular temperature profile (P3) and the increasing temperature profile (P4) have similar drying times and shortened the drying times to almost one of the low constant temperature (P1). These results show that it can be possible to reduce drying time by using non-constant temperature profiles.

Table 3. Finishing times of drying experiments (hours)

Temperature Profile	Drying Time (h)			
	Replications			Average
	I	II	III	
P1	24	21	18	21^{1}
P2	5	3	3	3.6^{3}
P3	10	8	7	8.3^{2}
P4	10	8	8	8.6^{2}
P5	4	4	4	4^{3}

The superscript numbers were used to show the statistically-different mean values according to the Duncan test ($p \leq 0.05$).

The measured brightness values (L*) of the fresh and dried samples of lemon balm were given in Table 4. The brightness values of fresh samples ranged from 41.36 to 47.79 probably because of uncontrolled variations in agronomic conditions from harvest to harvest. The brightness values (L*) of dried samples ranged from 30.14 to 40.14, which were lower than the ones of fresh samples. The temperature profiles P2, P3 and P5 decreased the brightness values more than the temperature profiles P1 and P4 did (Figure 2). The reason for this difference may be that the drying samples were exposed to a relatively high drying air temperature, 60 °C, for the temperature profiles P2, P3 and P5. The drying air temperatures over 50 °C is commonly considered to be high drying temperatures for the medicinal and aromatic plant, which causes considerable quality changes [5,6, 12-13].

Table 4. Brightness values (L*) of fresh and dried lemon balm samples

Temperature Profile	**Fresh Samples**			**Dried Samples**		
	Replications			**Replications**		
	I	II	III	I	II	III
P1	$45.60^{11,10}$	$44.30^{11,10,9}$	$45.60^{11,10}$	$36.30^{6,5,4}$	$38.54^{8,7,6}$	$40.14^{8,7}$
P2	$44.30^{11,10,9}$	$44.79^{11,10}$	$44.23^{11,10,9}$	$32.90^{3,2,1}$	$33.00^{3,2,1}$	$34.69^{5,4,3,2}$
P3	$46.09^{11,10}$	$46.46^{11,10}$	47.18^{11}	$34.16^{4,3,2}$	$32.43^{2,1}$	$34.87^{5,4,3,2}$
P4	$43.50^{10,9}$	$47.79^{11,10}$	$44.14^{11,10,9}$	$37.62^{7,6,5}$	$38.27^{7,6}$	$36.14^{6,5,4,3}$
P5	$45.28^{11,10}$	$41.36^{8,7}$	$44.18^{11,10,9}$	$33.14^{4,3,2,1}$	$34.88^{5,4,3,2}$	30.14^{1}

The superscript numbers were used to show the statistically-different mean values according to the Duncan test ($p \leq 0.05$).

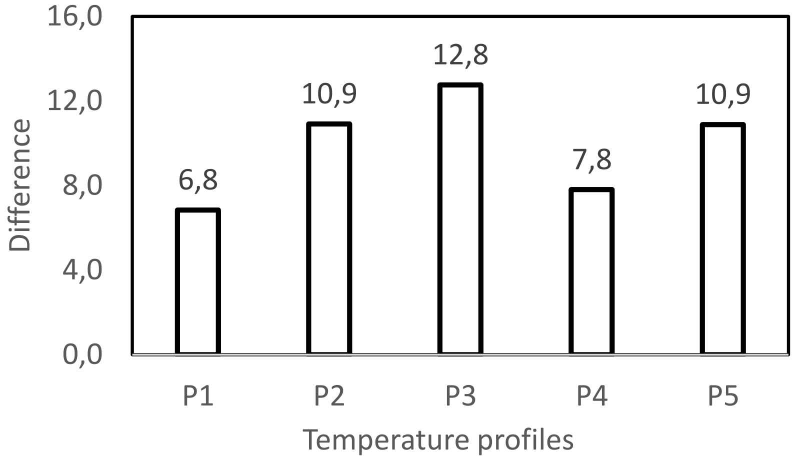


Figure 2. Differences of L* values of fresh and dried lemon balm samples

The measured redness/greenness values (a*) of the fresh and dried samples of lemon balm were given in Table 5.

Table 5. Redness/greenness values (a*) of fresh and dried lemon balm samples

Temperature Profile	**Fresh Samples**			**Dried Samples**		
	Replications			**Replications**		
	I	II	III	I	II	III
P1	$-15.43^{3,2,1}$	$-17.97^{3,2}$	$-15.46^{3,2,1}$	-7.98^{5}	-7.04^{5}	-6.78^{5}
P2	$-14.81^{3,2,1}$	$-15.97^{3,2,1}$	$-15.57^{3,2,1}$	-2.75^{6}	-2.04^{6}	-2.57^{6}
P3	$-16.73^{2,1}$	-17.36^{1}	$-16.19^{3,2,1}$	-2.72^{6}	-2.07^{6}	-2.04^{6}
P4	-11.31^{4}	$-14.85^{3,2,1}$	$-16.21^{3,2,1}$	-5.81^{5}	-5.51^{5}	-5.46^{5}
P5	$-14.86^{3,2,1}$	$-13.64^{4,3}$	$-14.93^{3,2,1}$	-2.60^{6}	-3.03^{6}	-1.00^{6}

The superscript numbers were used to show the statistically-different mean values according to the Duncan test ($p \leq 0.05$).

The redness/greenness values of fresh samples ranged from -17.97 to -11.31 probably because of uncontrolled variations in agronomic conditions from harvest to harvest. Negative a* values shows that fresh samples have a strong green color [14]. The redness/greenness values (a*) of dried samples ranged from -7.98 to -1.00, which were higher than the ones of fresh samples. The temperature profiles P2, P3 and P5 increased a* values more than the temperature profiles P1 and P4 did (Figure 3). The green color of lemon balm can be retained more by gradually increasing the temperature of drying air. This result shows that the green color is more vulnerable to high drying temperatures at the early phase of drying process.

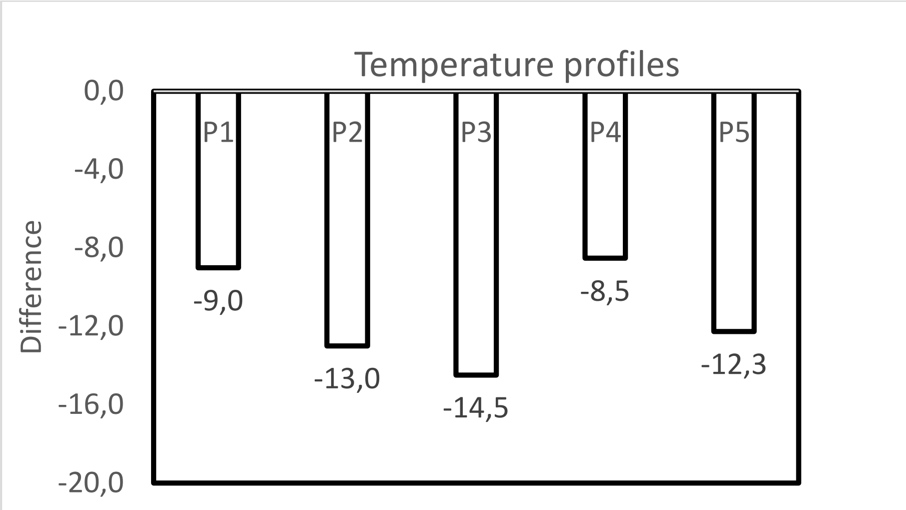


Figure 3. Differences of a* values of fresh and dried lemon balm samples

The measured yellowness and blueness values (b*) of the fresh and dried samples of lemon balm were given in Table 6.

Table 6. Yellowness/blueness values (b*) of fresh and dried lemon balm samples

Temperature Profile	Fresh Samples			Dried Samples		
	Replications			Replications		
	I	II	III	I	II	III
P1	$26.28^{6,5}$	$25.53^{6,5}$	$27.53^{8,7,6,5}$	17.13^{4}	$16.36^{4,3}$	$16.30^{4,3}$
P2	$25.25^{6,5}$	$26.47^{7,6,5}$	$27.84^{9,8,7,6}$	$14.55^{4,3,2,1}$	$12.95^{2,1}$	$13.17^{3,2,1}$
P3	$29.48^{9,8,7}$	30.72^{9}	$29.42^{9,8,7}$	$15.52^{3,2,1}$	$13.66^{3,2,1}$	$14.22^{4,3,2,1}$
P4	$24.95^{6,5}$	24.54^{5}	$30.22^{9,8}$	$15.80^{4,3,2}$	$16.03^{4,3,2}$	$16.14^{4,3,2}$
P5	$26.64^{7,6,5}$	$25.44^{6,5}$	$25.19^{6,5}$	$12.90^{2,1}$	$13.61^{3,2,1}$	12.22^{1}

The superscript numbers were used to show the statistically-different mean values according to the Duncan test ($p \leq 0.05$).

The yellowness/blueness values of fresh samples ranged from 24.54 to 30.22 probably because of uncontrolled variations in agronomic conditions from harvest to harvest. Positive b* values shows that fresh samples also have a strong yellow color [9]. Therefore, the fresh lemon balm plants has a yellowish green color based on the positive b* values and negative a* values. The yellowness/blueness values (b*) of dried samples ranged from 12.22 to 16.36, which were lower than the ones of fresh samples. All drying air temperature profiles decreased the b* values. Even though the differences among the b* values of dried samples were statistically less noticeable, the exposure of drying plants to high drying temperatures at the early period of drying process has a relatively more destructive impact (Figure 4).

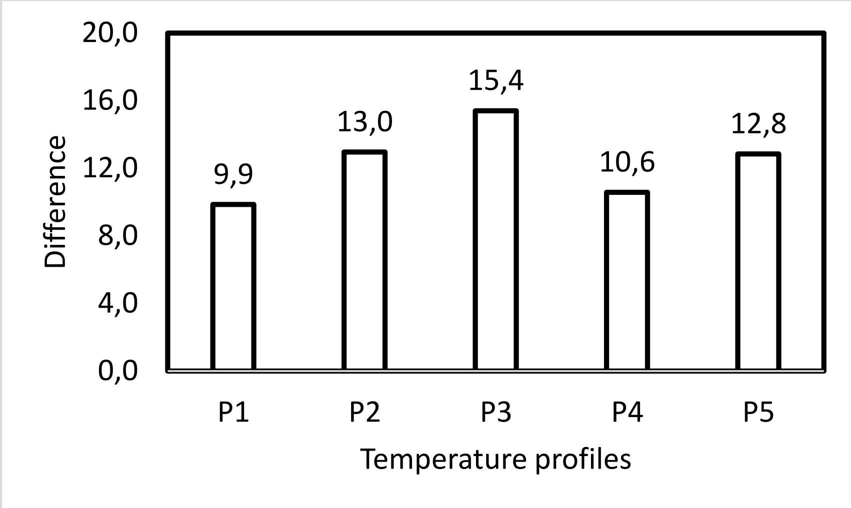


Figure 4 Differences of b* values of fresh and dried lemon balm samples

The essential oil contents of the fresh and dried lemon balm samples are given in Table 7. Table 7 shows that the essential oil content of the fresh samples varied from 0.12 to 0.32 mL·100 g dry matter^{-1} probably because of uncontrolled variations in agronomic conditions from harvest to harvest as seen in color values. It was reported that the essential oil content of fresh lemon balsam samples ranged from 0.01-0.25 mL (100 g dry matter^{-1}) in a previous literature [3]. The results obtained from both studies are similar. The essential oil content of fresh lemon balm plants is very sensitive to the uncontrolled variations of agronomic conditions even though the same agronomic practices were followed for all harvests.

Table 7. The essential oil contents of the fresh and dried lemon balm samples

Temperature Profile	Replications	Essential oil quantities (mL·100 g dry matter^{-1})		Loss Percent (%)	Average Loss Percent (%)
		Fresh samples	Dried Samples		
P1	I.	0.12	0.095	20.83	24.29^3
	II.	0.259	0.189	27.03	
	III.	0.32	0.24	25.00	
P2	I.	0.12	0.042	65.00	63.96^1
	II.	0.32	0.106	66.88	
	III.	0.32	0.128	60.00	
P3	I.	0.259	0.128	50.58	42.27^2
	II.	0.32	0.191	40.31	
	III.	0.22	0.141	35.91	
P4	I.	0.259	0.168	35.14	34.61^2
	II.	0.32	0.218	31.88	
	III.	0.22	0.139	36.82	
P5	I.	0.259	0.152	41.31	41.55^2
	II.	0.32	0.177	44.69	
	III.	0.22	0.135	38.64	

The superscript numbers were used to show the statistically-different mean values according to the Duncan test ($p \leq 0.05$).

Drying caused the reduction of essential oil contents but drying air temperature profiles had a strong impact on final essential oil contents. The constant low drying air temperature profile (P1) caused 24.29% average lost in the essential oil contents of dried samples compared to the essential oil contents of fresh samples. This average loss increased to 63.96% for the constant high temperature profile (P2). On the other hand, the increasing temperature profile (P4) limited the essential oil loss compared to the constant high temperature profile (P2). The other two drying air temperature profiles (P3 and P5) also reduced the essential oil content loss compared to the constant high temperature profile (P2); however, their average loss percent was higher than the average loss percent of P2. These results show that the essential oil loss of lemon balm during drying increases drastically with the increase of drying air temperature value. On the other hand, varying drying air temperature from a low value to a high value over time can slow down the essential oil loss.

4. Conclusions

The loss of essential oil and the discoloration of fresh lemon balm samples occurred during drying but the amounts of these changes depended on the selected temperature profile of drying air. The maximum undesirable quality changes occurred at the constant 60 °C temperature profile of drying air while the minimum quality changes occurred at the constant 35 °C temperature profile of drying air. Even though the drying with the constant 35 °C had minimum quality changes, it took 21 hours of drying time to reduce the moisture content of lemon balm samples. On the other hand, increasing drying air temperature gradually from 35 °C to 60 °C in 8 hours shortened the drying time to 8.6 hours while reducing the essential oil loss and discoloration of fresh lemon balm samples more distinguishably compared to the constant 60 °C, triangular or the decreasing temperature profiles.

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