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Determining of effect of different planting densities on yield and quality in Summer Savory (*Satureja hortensis* L.)

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Abstract

The aim of the experiment was to detect divergent inter-row and intra-row spacings on the yield, yield attributing characteristics and quality characteristics of sater (*Satureja hortensis* L.). The experiments were conducted in experimental field of ESOGU, Agricultural Faculty using Randomized Complete Block design with split plot arrangement in 2014 and 2015. The experiments were replicated 3 times. The treatments included three inter row distances (20, 40 and 60 cm) were randomized in the main plots and three intra row distances (10, 20 and 30 cm) randomized in the sub-plots. The influence of various inter and intra row spacings on plant height, habitus diameter, fresh herb yield per plant, fresh leaf yield per plant, dry leaf yield per plant, dry leaf yield per hectare, volatile oil ratio, volatile oil yield and volatile oil composition of summer savory was determined in these experiments. Increasing plant density reduced both the yield components and yield of individual plants while increasing dry leaf and volatile oil yield per unit area. İncreasing inter row and intra row spacings resulted in significantly higher habitus diameter, fresh herb yield per plant, fresh leaf yield per plant, dry leaf yield per plant. The highest dry leaf yield per hectare (3.4 t per hectare) and volatile oil yield per hectare (84,8 l per hectare) were obtained from plant density of 20 × 10 cm. The main compounds of volatile oil samples were carvacrol and γ-terpinene. These two main compounds constituted 80.92-85.49% of the total essential oil.

Key words: volatile oil ratio and composition, planting densities, quality, summer savory, *Satureja hortensis* L., yield.

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Farklı dikim sıklıklarının Sater (*Satureja hortensis* L.) bitkisinde verim ve kalite üzerine etkisinin belirlenmesi

Özet

Bu çalışmanın amacı, farklı sıra arası ve sıra üzeri mesafelerinin sater (*Satureja hortensis* L.) bitkisinin verim, verim komponentleri ve kalite özellikleri üzerine etkisini belirlemektir. Denemeler, 2014 ve 2015 yıllarında tesadüf bloklarında bölünmüş parseller deneme desenine göre ESOGU Ziraat Fakültesi deneme tarlasında yürütülmüştür. Denemeler 3 tekerrürlü olarak kurulmuştur. Ana parsellerde 3 sıra arası (20, 40 ve 60 cm) ve alt parsellerde 3 sıra üzeri mesafe (10, 20 ve 30 cm) yerleştirilmiştir. Bu çalışmada sater bitkisinde farklı sıra arası ve sıra üzeri mesafelerin bitki boyu, habitus çapı, bitkide taze herba verimi, bitkide taze yaprak verimi, bitkide kuru yaprak verimi, hektara kuru yaprak verimi, uçucu yağ oranı, hektara uçucu yağ verimi ve uçucu yağ bileşeni belirlenmiştir. Artan bitki sıklığı, birim alana kuru yaprak ve uçucu yağ verimini arttırırken, tek bitkilerin hem verim ve hem de verim komponentlerini azaltmıştır. Artan sıra arası ve sıra üzeri mesafeler, önemli ölçüde daha yüksek habitus çapı, bitkide taze herba verimi, bitkide taze yaprak verimi ve bitkide kuru yaprak verimi üretmiştir. En yüksek kuru yaprak verimi (3.24 t ha^{-1}) ve uçucu yağ verimi (84.8 l ha^{-1}) 20x10 cm bitki sıklığından elde edilmiştir. Uçucu yağ örneklerinin ana bileşenleri karvakrol ve γ-terpinendir. Bu iki ana bileşen, toplam uçucu yağın %80.92-85.49 unu oluşturmuştur.

Anahtar kelimeler: dikim sıklıkları, kalite, zahter, *Satureja hortensis* L., uçucu yağ içeriği ve bileşimi, verim.

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1. Introduction

Summer savory (*Satureja hortensis* L., Lamiaceae) is a known spice crop in certain parts of the world. Sater is distributed in the natural flora of Turkey, Iraq and Iran and the Caucasus, especially in Southern European countries bordering the Mediterranean and has been started to be grown in many parts of the world in the last 20-30 years. [1]. The leaves of the plant have been used as tea, as well as added to commercial seasoning mixtures to add fragrance and flavor to many foods [2]. In addition, summer savory has been used for many years as a traditional drug to cure different diseases such as cramps, muscle ailments, nausea, digestive problems, diarrhea and infectious ailments [3, 4]. The volatile oil of summer savory has many bioactivities including anti-oxidant, antibacterial and anti-fungal activities. The plant has widespread use in the food, beverage and parfumery industries all over the world [5, 6, 7, 8]. The economic importance of summer savory cultivation varies depending on the dry leaf yield, yield and ratio of volatile oil, as well as the contents of carvacrol and γ-terpinene in the volatile oil [6].

Environmental factors, agronomic practices and genetic makeup of plant materials used in cultivation affect growth, development, yield and quality of medicinal and aromatic plants [9, 10, 11, 12, 13]. Plant density is an important agronomic applications in terms of making more efficient use of ecological factors such as light, soil moisture and fertilizers. Insufficient plant density not only results in less efficient use of water, nutrients and solar radiation, but also increases soil erosion, water evaporation and weed infestation. On the other hand, excessive plant density is to increase the plant to plant competition and ultimately decreases the yield, yield components and quality characteristics of cultivated crop [13, 14, 15, 16]. It is of great importance to sow/plant the crops in suitable stands in order to eliminate the negative effects caused by insufficient or excessive plant density. The studies of [17] on fennel showed that the increment in the plant density rised significantly the fruit yield. A study on coriander reported that the influence of plant densities was significant on fruit yield and yield parameters[18] . Also, [19] revealed that the volatile oil yield of summer savory in sole crop treatment was significantly higher than in intercrop and the highest volatile oil yield was the density of 40 plants m^{-2}. [1] showed that the plant density in summer savory had significant influences on most of the morphological characteristics, but had no significant influence on dry shoot yield.

The aim of the experiments were to detect the influence of diverse inter-row distances and intra-row distances on the yield, yield components and quality characteristics of *Satureja hortensis* L. under Eskişehir ecological conditions. The most important property of these studies were that the influence of diverse inter-row and intra-row spacings on the volatile oil profile was determined.

2. Materials and methods

The field studies were conducted at the field of the University of ESOGU, Faculty of Agriculture (39º 45΄ N, 30º 31΄E, altitude 732 m) in 2014 and 2015. Climatic values for experimental years were given in Table 1. While the average temperatures of the experimental years for the vegetation period of the plant (April-July) were approximately the same as the value of long years, the precipitation values of 2014 was lower than the value of long years and the value of 2015 was higher than the value of long years. It was observed that the maximum temperatures of the experimental years were higher when compared to the long years. The minimum temperatures recorded in the experimental years were lower than the values of the long years (Table 1).

Table 1. Meteorological data of the experiment years*

Eskişehir	Years	April	May	June	July	Total/Mean
Average Temperature (°C)	1960-2012	10.2	15.1	19.1	21.7	16.53
	2014	11.5	15.1	18.5	22.6	16.93
	2015	7.9	15.5	17.1	22.1	15.65
The maximum temperature (°C)	1960-2012	16.8	21.8	25.9	28.9	23.35
	2014	26.6	28.9	34.9	36.4	31.70
	2015	26.3	30.8	28.2	37.2	30.63
The minimum temperature(°C)	1960-2012	3.7	7.8	11.2	13.8	9.13
	2014	-3.7	3.8	6.9	10.2	4.30
	2015	-4.7	3.3	6.1	10.1	3.70
Monthly of precipitation (mm)	1960-2012	43.4	44.4	31.0	13.2	132.0
	2014	15.2	27.2	70.6	7.5	120.5
	2015	26.6	47.8	151.1	-	225.5

Source: *Eskişehir Regional Meteorological Service.

Physico-chemical analyses of the soil samples taken from the trial plots were made and the data obtained are given in Table 2. Soil samples had organic matter ratios of 2.4% and 1.7%, low P_2O_5 (5.49 and 4.97 kg da^{-1}), medium

K_2O (210.4 and 232.3 kg da^{-1}), an alkaline pH (7.8 and 7.1), a salt percentage of 0.021 and 0.040% and a $CaCO_3$ percentage 6.61 and 5.22%, respectively (Table 2).

Table 2. Properties of of soils in trial plots*

Structure (0-40 cm)	**Lime (%)**	**Total Salt (%)**	**Plant-Available Phosphorus (P_2O_5) (kg da^{-1})**	**Plant-Available Potassium (K_2O)(kg da^{-1})**	**pH**	**Organic Matter (%)**
(2014) Loamy	6.61	0.021	5.49	210.4	7.8	2.4
(2015) Loamy	5.22	0.040	4.97	232.3	7.1	1.7

*ESOGU Faculty of Agriculture Soil Analysis Laboratory

In this study, seed of summer savory population purchased from Black Sea Agricultural Research Institute Samsun/Turkey was used as plant materials. Seeds of summer savory were sown in the nursery prepared with a mixture of sand (1/3), soil (1/3) and manure (1/3) in nursery on 13.03.2014 and 11.03.2015. The nursery was irrigated and control of weeds was done when necessary. When plantlets reached 5-10 cm length (about 40-45 days later) plantlets in the nursery were transplanted to experimental fields in different plant densities. The field trials were conducted in using Randomized Complete Block design with split plot arrangement in 2014 and 2015. The experiments were replicated 3 times. The treatments included three different inter-row distances (20, 40 and 60 cm) were randomized in the main plots and three intra-row distances (10, 20 and 30 cm) randomized in the sub-plots. Each plot had 6 rows with 5 m. The plants in the trial plots were irrigated with the drip irrigation method, taking into account their water needs. 100 kg N and 40 kg P2O5 per hectare fertilizer was applied to the experimental plots in both two years [6, 20]. Summer savory was cut at aproximately 50% of flowering period (11.07.2014 and 16.08.2015) by cutting 5-6 cm above the soil [21]. Fresh herbage values were weighted by a digital scale with accuracy of 0.01 g. Fresh leaf herbage data were also detected by weighting leaves of summer savory plants. Fresh leaves were dried at 35 oC ±2 temperature in stove for 24 hours and weighted; in this way, dry leaf yield was calculated.

Volatile oil ratios of leaf samples (100 g) were determined by water distillation method using Clevenger device. The amount of essential oil obtained as a result of the distillation carried out for three hours was recorded as ml per 100 g [22]. Samples of volatile oil were stored in refrigerator at 4 ° C until the composition analysis.

A gas chromatography (GC) system (Agilent Technologies, 7890B) equipped with a flame ionization detector (FID) and coupled to a mass spectrometry detector (MSD) (Agilent Technologies, 5977A) was used for detection of the volatile oil profile. The column was HP-Innowax (Agilent 19091N-116: 60 m × 0.320 mm internal diameter and 0.25 μm film thickness). The carrier gas was Helium (99.999%) with 1.3 mL min-1 flow rate. Injection volume was set at 1 μl (20 μL EO was dissolved in 1 mL n-Hexane). The injection mode was split (40:1). The samples analyzed with the column held initially at 70 °C after injecting with 5 min hold time. Afterward, the temperature rised to 160 °C with 3 °C min-1 heating ramp and 5 min hold time. Eventually, the temperature reached to 250 °C with 6 °C min-1 heating ramp and 5 min hold time. The injector, detector and ion source temperatures were 250 °C, 270 °C and 230 °C, respectively. MS scan range was (m/z): 50-550 atomic mass units (AMU) under electron impact (EI) ionization (70 eV).

The identifications of the EO compounds were determined by the comparison of retention indices, mass spectra by the computer library database of US National Institute of Standards and Technology (NIST), Wiley libraries, other published mass spectra data and our database. The components percentage was obtained based on GC-FID analyses. No response factors were calculated.

All analyses were performed with the MSTAT-C program. The combined values of the parameters examined in 2014 and 2015 were analyzed according to the Randomized Complete Block design with a split plot arrangement. The Fisher's least significant difference (LSD) test was used to test for significant differences [23].

3. Results

As is known, there are many agronomic applications that are effective on the yield, yield components and quality of the herbal product in medicinal aromatic plants [11, 12, 13]. Optimization of planting density in the unit area is one of the most important agronomic applications affecting yield and quality [24]. Optimization of planting density per unit area promotes the growth and development of cultivated plants by minimizing competition among plants in terms of environmental factors such as soil water, solar radiation and nutrients [25]. In addition, proper plant density is to increase the rate at which the plants benefit from solar radiation by optimizing the area covered with plants in the field [26]. Thus, high yield and quality is achieved in crop production.

Data of variance analysis were shown in Table 3. While different inter-row spacings caused statistically significant variation in plant height values ($p<0.05$), intra-row distances did not cause no significant variation. The highest plant height value (31.54 cm) was determined at 40 cm inter-row distance, while the lowest value (30.43 cm) was determined at 20 cm inter-row distance. In the inter-row x intra-row interaction, the highest plant height value (32.17 cm) was obtained from 60 x 10 cm plant density. The average plant height value obtained from the study was determined as 31.16 cm. This situation can be explained by the positive effect of reaching the optimal level of unit area for plants on the growth and development.

While the different inter-row and intra-row spacings on the diameter of habitus values were statistically significant at 1%, their interaction was statistically significant at the 5%. In the study, the average habitus diameter value was determined as 22.32 cm. The highest habitus diameter value was obtained as 27.85 cm from 60 x 30 cm plant density, while the lowest value (17.69 cm) was obtained from 20 x 10 cm plant density (Table 3). The fact that the highest habitus diameter value was obtained from the largest planting density (60 x 30 cm) can be explained by the positive effect of the increase in the growth area per plant on plant growth and development.

The different inter-row spacings and intra-row spacings on fresh herb yield per plant were statistically significant at 1% probability. While the mean highest fresh herb yield per plant (133.17 g plant^{-1}) was 60 cm inter-row spacing, the mean lowest value (77.33 g plant^{-1}) was obtained from 20 cm. Likewise, the mean highest fresh herb yield per plant (127.54 g plant^{-1}) was obtained from 30 cm intra-row distance, while the lowest value (86.30 g plant^{-1}) was obtained from 10 cm intra-row distance. Average fresh herb yield in the study was determined as 105.99 g plant^{-1} (Table 3).

While the different inter-row and intra-row spacings on fresh leaf yield per plant were statistically significant at 1% probability level, their interaction was statistically significant at the 5% probability level. The highest yield of fresh leaves per plant was obtained from 60 x 30 cm plant density as 104.67 g plant^{-1}, while the lowest yield value was obtained from 20 x 10 cm as 38.58 g plant^{-1}. Average fresh leaf yield in the study was determined as 65.01 g plant^{-1} (Table 3).

The different inter-row and intra-row spacings on dry leaf yield per plant were statistically significant at 1%, while their interaction was statistically significant at the 5%. The highest yield of dry leaves per plant was obtained from 60 x 30 cm plant density as 21.97 g plant^{-1}, while the lowest yield value was obtained from 20 x 10 cm as 8.11 g plant^{-1}. Average dry leaf yield in the study was determined as 13.46 g plant^{-1} (Table 3). The variation in dry leaf yield per plant can be explained by the increase of unit area per plant. Increasing the unit area per plant encouraged the growth and development of the plants, while the decrease in the unit area per plant prevented the growth and development by encouraging the competition between the crops.

As demonstrated in Tables 3, the different inter-row and intra-row distances and their interaction significantly influenced the dry leaf yield per hectare. The highest dry leaf yield per hectare was calculated as 3.24 t ha^{-1} at 20 x 10 cm planting density, while the lowest value was 0.94 t ha^{-1} from 60 x 30 cm planting density. This situation showed that the highest yield of dry leaves per hectare was calculated from the narrowest inter-row and intra-row distance. This indicated that the influence of increasing the number of plants per hectare on total yield is more important than the increase in single crop yield.

Table 3. The influence of different inter-row and intra-row spacings on yield and yield components of summer savory

	Plant Height (cm)				**Diameter of Habitus (cm)**			
Inter-Row	**Intra-row**				**Intra-row**			
	10 cm	**20 cm**	**30 cm**	**Mean**	**10 cm**	**20 cm**	**30 cm**	**Mean**
20 cm	30.07	30.42	30.80	30.43 B	17.69 f	19.66 e	21.00 d	**19.45 B**
40 cm	31.67	31.57	31.40	31.54 A	20.52 d	20.08 d	22.65 c	**21.08 B**
60 cm	32.17	30.70	31.62	31.49 A	25.55 b	25.89 b	27.85 a	**26.43 A**
Mean	31.30	30.89	31.27	31.16	21.26 C	21.88 B	23.83 A	22.32
	C.V.(%): 2.95 **L.S.D. (%):** Inter-row: 0.77. **F$_{Values}$:** Inter-row: 10.47*; Intra-row: 0.77ns; Inter-row × Intra-row: 1.37ns.				**C.V.(%):** 14.74 **L.S.D. (%):** Inter-row: 0.46; Intra-row: 0.85; Inter-row × Intra-row: 1.06. **F$_{Values}$:** Inter-row: 2635.37**; Intra-row: 46.34**; Inter-row × Intra-row: 3.27*.			
	Fresh Herb Yield (g per plant)				**Fresh Leaf Yield (g per plant)**			
Inter-Row	**Intra-row**				**Intra-row**			
	10 cm	**20 cm**	**30 cm**	**Mean**	**10 cm**	**20 cm**	**30 cm**	**Mean**
20 cm	60.63	76.45	94.91	77.33 C	38.58 e	51.33 d	61.19 c	50.37 B
40 cm	86.68	107.12	128.63	107.48 B	50.03 d	65.50 c	73.18 b	62.91 B
60 cm	111.60	128.85	159.07	133.17 A	59.83 c	80.72 b	104.67 a	81.74 A

Table 3. Continues

Mean	86.30 C	104.14 B	127.54 A	105.99	49.48 C	65.85 B	79.68 A	65.01
	C.V.(%): 27.68 **L.S.D.(%):** Inter-row: 13.14; Intra-row: 7.17. F_{Values}: Inter-row: 191.85**; Inter-row: 155.38**; Inter-row × Intra-row: 1.75ns.				**C.V.(%):** 29.95 **L.S.D. (%):** Inter-row: 15.86; Intrarow: 8.97; Inter-row × Intra-row: 11.08. F_{Values}: Inter-row: 42.00**; Intra-row: 53.03**; Inter-row × Intra-row: 3.30*.			
	Dry Leaf Yield (g per plant)				**Dry Leaf Yield per Hectare (t per hectare)**			
Inter-Row	**Intra-row**				**Intra-row**			
	10 cm	**20 cm**	**30 cm**	**Mean**	**10 cm**	**20 cm**	**30 cm**	**Mean**
20 cm	8.11 c	10.79 b	12.35 b	10.22 C	3.24 A	2.26 B	1.65 D	2.17 A
40 cm	10.44 b	13.75 b	15.16 b	13.68 B	1.92 C	1.52 D	1.28 D	1.61 B
60 cm	12.10 b	16.52 b	21.97 a	16.49 A	1.34 D	1.06 E	0.94 E	1.29 C
Mean	10.42 B	13.11 B	16.86 A	13.46	2.38 A	1.57 B	1.11 C	1.69
	C.V.(%): 30.13 **L.S.D. (%):** Inter-row: 3.07; Intra-row: 1.79; Inter-row × Intra-row: 2.21. F_{Values}: Inter-row: 47.03**; Intra-row: 57.68**; Inter-row × Intra-row: 5.11*.				**C.V.(%):** 41.06 **L.S.D. (%):** Inter-row: 0.26; Intra-row: 0.19; Inter-row × Intra-row: 0.33. F_{Values}: Inter-row: 268.67**; Intra-row: 104.33**; Inter-row × Intra-row: 17.65**.			
	Volatile Oil Ratio (%)				**Volatile Oil Yield (l per hectare)**			
Inter-Row	**Intra-row**				**Intra-row**			
	10 cm	**20 cm**	**30 cm**	**Mean**	**10 cm**	**20 cm**	**30 cm**	**Mean**
20 cm	2.59	2.47	2.80	2.91	84.8 a	56.3 b	46.2 b	61.4 A
40 cm	2.98	2.92	2.93	2.92	57.1 b	44.3 c	37.7 c	45.5 B
60 cm	3.15	3.38	3.26	3.00	42.2 c	35.8 d	30.5 d	38.1 B
Mean	2.62 B	2.94 AB	3.26 A	2.94	62.4 A	46.4 B	36.2 B	48.3
	C.V. (%): 10.97 **L.S.D. (%):** Inter-row: 0.37. F_{Values}: Inter-row: 32.11ns; Intra-row: 0.57**; Inter-row × Intra-row: 1.48ns.				**C.V.(%):** 33.85 **L.S.D. (%):** Inter-row: 1.06; Intra-row: 0.91; Inter-row × Intra-row: 1.12. F_{Values}: Inter-row: 66.61**; Intra-row: 31.89**; Inter-row × Intra-row: 4.13*.			

C.V.: Coefficient of Variance; L.S.D.: Least Significant Differences; ns: not significant; *: p<0.05 and **: p<0.01

The statistical analysis made by combining the values of the two-year showed that different inter-row spacings did not have a significant effect on the volatile oil ratio, but different intra-row distances had a significant influence on the volatile oil ratio (at 1% probability level). In the study conducted, the highest volatile oil ratio was taken as 3.26% from 30 cm intra-row distance, while the lowest value was 2.62% from 10 cm intra-row spacing. The average rate of volatile oil obtained from the study was determined to be 2.94%. Changing plant density is to cause variation in volatile oil ratio due to its effects on the micro ecology of plants.

As it is known, volatile oil yield per hectare is to determine by the volatile oil rate and dry leaf yield per hectare. Volatile oil yield was significantly influenced by different inter-row distance (p<0.01), intra-row distance (p<0.01) and their interaction (p<0.05). The highest volatile oil yield per hectare was determined as 84.8 l from the planting density of 20 x 10 cm, while the lowest yield was obtained as 30.5 l from the planting density of 60 x 30 cm. The average essential oil yield per hectare obtained from the study was determined as 48.3 l. As shown in these values, the application (20 x 10 cm) with the highest dry leaf yield ha^{-1} produced the highest essential oil yield. The data obtained showed that there were significant increases in dry leaf and volatile oil yield depending on the increasing number of plants per unit area. It were reported that the content and yield of volatile oil in medicinal and aromatic crops vary depending on genotype of plant, location of cultivation, fertilization, harvest times as well as plant density [27, 28].

The main compounds of essential oil from summer savory leaf were carvacrol (51.9-62.0%), γ-terpinene (22.35-32.60%) and p-cymene (3.86-5.69%). These three main components accounted for 88.45-90.04% of the total essential oil. The highest carvacrol ratio (62%) was obtained from the planting density of 20 × 30 cm in 2014, while the lowest value (51.9%) was determined from the 60 × 30 cm plant density in 2015. On the other hand, the lowest γ-terpinene ratio (22.35%) was obtained from the plant density of 20 × 30 cm in 2014, while the highest value (32.6%) was determined in the plots in which 60 × 30 cm planting density was made in 2015. Although carvacrol, an oxygenated monoterpene compound, did not react regularly to various planting density, its response to changing climatic conditions was more regular over the years and 2014 year gave higher carvacrol values compared to 2015. In contrast to carvacrol, terpinene, a monoterpene hydrocarbon structure, was higher in 2015 compared to 2014.

Table 4. The ınfluence of various plant densities and years on the volatile oil profile of summer savory

Essential Oil Components	**Plant Density (cm)**																	
	20×10		**20×20**		**20×30**		**40×10**		**40×20**		**40×30**		**60×10**		**60×20**		**60×30**	
	2014	**2015**	**2014**	**2015**	**2014**	**2015**	**2014**	**2015**	**2014**	**2015**	**2014**	**2015**	**2014**	**2015**	**2014**	**2015**	**2014**	**2015**
alpha-pinene	0.69	1.13	1.11	1.22	0.98	1.45	1.04	1.28	1.08	1.26	1.14	1.15	1.14	1.01	1.11	1.80	1.10	1.18
alpha-thujene	0.49	1.56	0.90	1.57	0.75	1.91	0.92	1.76	0.98	1.75	0.94	1.62	0.95	1.50	0.86	1.62	1.04	1.41
beta-pinene	0.26	0.52	0.46	0.59	0.34	0.68	0.43	0.59	0.42	0.59	0.43	0.53	0.42	0.44	0.40	0.79	1.49	0.51
beta-myrcene	1.13	2.26	1.88	2.32	1.48	2.84	1.86	2.54	1.98	2.53	1.91	2.26	1.94	2.22	1.70	2.22	1.09	2.34
alpha-terpinene	1.84	3.62	2.91	3.65	2.30	4.63	2.79	4.07	3.01	4.06	3.00	3.69	3.11	3.59	2.78	3.33	2.13	3.50
limonene	0.21	0.34	0.30	0.34	0.26	0.44	0.29	0.37	0.30	0.38	0.31	0.33	0.31	0.32	0.28	0.57	0.30	0.36
γ-terpinene	27.6	30.5	27.14	30.23	22.35	25.42	25.43	27.33	26.43	27.11	26.77	30.38	27.89	29.56	24.63	27.63	28.47	32.60
p-cymene	5.61	4.14	4.79	4.34	5.69	4.70	4.55	4.20	4.26	4.19	5.59	3.86	5.41	4.46	5.02	4.67	4.58	3.95
terpinen-4-ol	0.62	0.32	0.53	0.35	0.55	0.44	0.42	0.38	0.41	0.38	0.68	0.26	0.64	0.27	0.67	0.53	0.53	0.36
beta-caryophyllene	1.80	0.87	1.20	0.92	1.71	0.91	1.23	0.90	1.30	0.91	1.20	0.90	1.17	0.88	1.25	0.91	1.41	0.73
beta-bisabolene	1.01	0.53	0.83	0.56	1.12	0.51	0.93	0.56	0.99	0.57	0.77	0.64	0.68	0.69	0.80	0.44	0.85	0.55
carvacrol	57.9	53.9	57.6	53.3	62.0	55.5	59.6	55.3	58.5	55.6	56.5	54.0	55.8	54.7	60.2	53.8	56.3	51.9
unidentified	0.35	0.33	0.27	0.57	0.43	0.49	0.48	0.64	0.28	0.64	0.71	0.32	3.35	0.32	0.24	1.69	0.64	0.53

4. Conclusions and discussion

Results of the experiment indicated that effects of different inter-row and intra-row spacings on plant height, diameter of habitus, fresh herb yield per plant, fresh leaf yield per plant, dry leaf yield per plant, dry leaf yield per hectare, volatile oil content and volatile oil yield were significant. The decreasing plant densities produced higher plant height, diameter of habitus, fresh herb yield per plant, fresh leaf yield per plant, dry leaf yield per plant, and volatile oil content. While the highest dry leaf yield per hectare and essential oil yield per hectare were obtained from the highest plant densities. Our findings regarding the influence of varying plant densities on yield and yield constituents were consistent with the findings obtained by [25, 29, 30, 31] and [32]. At the same time, the yield, yield components and quality values of the summer savory obtained from this study were supported by the values of [20] and [33]. But our values differed with their findings of [21] and [34]. This situation may be attributed to the difference of ecological conditions in which the studies are carried out.

The essential oil components of the aromatic plants differ depending on the origin/genotype of the plant used in the cultivation, the climate and soil properties of the region where it is cultivated, and the cultivation practices. Depending on the years of experiment, changing climate and soil factors had been effective on the chemical profile of the volatile oil. Similarly, the plant density, an important agronomic practice, also affects the chemical profile of the volatile oil by changing the micro ecological conditions present for each plant [35].

When the results obtained from the experiment were evaluated, it was observed that the most appropriate plant density for summer savory cultivation under Eskişehir ecological condition was 20 × 10 cm. The use of 20 × 20 cm instead of 20 × 10 cm in the plant density resulted in a 50% decrease in the number of seedlings per unit area, while the dry leaf and volatile oil yield per hectare decreased by 30% and 34%, respectively. Considering the cost of this situation, the plant density of 20 x 20 cm can be suggested as an alternative.

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