Ciência Rural, Santa Maria, v.54:03, e20220538, 2024 http://doi.org/10.1590/0103-8478cr20220538
ISSNe 1678-4596
BIOLOGY

The biomass and essential oil production of oregano hybrids cultivated under Central Anatolian climatic conditions

Reyhan Bahtiyarca Bağdat[1*]

[1]Central Research Institute of Field Crops (CRIFC), Gayret mah. Şehit Cem Ersever cad. No:9/11 06170, Yenimahalle, Ankara, Türkiye. E-mail: reyhan.bagdat@tarimorman.gov.tr. [*]Corresponding author.

ABSTRACT: Flora of Türkiye is hosting many *Origanum* sp. and spp. valuable members of Lamiaceae, including outstanding endemic species and hybrids. Those are having a number of using field and still meeting the World's major demand. Five combinations of artificial Oregano hybrids were cultivated in Ankara ecological conditions. Among those species; *Origanum minutiflorum* and *Origanum onites* are endemic to the flora of Türkiye and the combinations of those hybrids are very valuable and unique. According to the field studies results; the highest green herb yield was provided from H4 as 439.93g and from H5 as 317.26 g x plant^{-1}. H2 and H3 showed the highest green leaf yield by 278.69 and 244.33 g x plant^{-1}, and the highest leaf ratio (%). The essential oils ranged between 4.20% and 5.96%, Carvacrol predominated in the hybrids at; 77.90% (H1), 61.26% (H3) and 26.99% (H4), 72.09 (H5), and linalool at 45.86% (H2).
Key words: *origanum* hybrids, yield parameters, essential oil components, carvacrol.

A produção de biomassa e óleo essencial de híbridos de orégano cultivados sob condições climáticas da Anatólia Central

RESUMO: A flora da Turquia hospeda muitos *Origanum* sp. e spp. membros importantes de Lamiaceae, incluindo espécies endêmicas excepcionais e híbridos. Cinco várias combinações de híbridos artificiais de orégano foram cultivadas em condições ecológicas de Ancara. Entre essas espécies, *Origanum minutiflorum* e *Origanum onites* são endêmicos da flora Turca e as combinações desses híbridos são muito valiosas e únicas. De acordo com os resultados dos estudos de campo, a maior produção de erva verde foi obtida do H4 com 439,93g e do H5 com 317,26 g x planta-1. H2 e H3 apresentaram a maior produção de folhas verdes em 278,69 e 244,33 g x planta^{-1}. Os óleos essenciais variaram entre 4,20% e 5,96%. O carvacrol predominou nos híbridos 77,90% (H1), 61,26% (H3) e 26,99% (H4), 72,09 (H5), e linalol a 45,86% (H2).
Palavras-chave: híbridos de *origanum*, parâmetros de rendimento, componentes de óleo essencial, carvacrol.

INTRODUCTION

Türkiye supplies around 70% of the World's oregano consumption with a large oregano production potential. The natural flora of Türkiye, having a remarkable endemic richness, comprises important species including *Origanum vulgare* L. subsp. *hirtum* (Link) Ietswaart, *Origanum majorana* L., *Origanum minutiflorum* O. Schwarz et P.H. Davis (endemic), *Origanum syriacum* L. var. *bevanii* (Holmes) and *Origanum onites* L. (syn: *O. smyrneum*), being the most valuable one for its production and commercial values. Türkiye is a vital gene center of diversity of the genus. Represented by 21 species with three subspecies (24 taxa) and 13 hybrids, of which 25 are endemics to Türkiye (DIRMENCI et al., 2018; DIRMENCI et al., 2019).

Genetic adaptation is one of the good alternatives in which a population or species can avoid extinction caused by rapid environmental changes. Hybridization may enhance the adaptive potential of a population (HAMILTON & MILLER 2016; CHAN et al., 2018). Chromosome number and genome size can provide complementary data that may be useful to characterize the genus Origanum. The chromosome number of *Origanum* sp. and spp.'s are 2n=30, and there isn't any obstacle to interspecific hybridization, which led to great genetic variability within different Origanum species regarding their biomass yield and increase their quality characteristics (BAKHA et al. 2017). By means of this advantage, hybrid Oregano species were interbred in controlled conditions, and hybrids of *O. minutiflorum* x *O. majorana* (H1), *O. vulgare* x *O. majorana* (H2), *O. syriacum* x *O.*

Received 09.28.22 Approved 06.02.23 Returned by the author 08.16.23
CR-2022-0538.R1
Editors: Rudi Weiblen Diego Follmann

vulgare (H3), *O. syriacum* x *O. minutiflorum* (H4) and *O. onites* x *O. vulgare* (H5) which some of those are endemic of the flora of Türkiye (such as *O. minutiflorum* and *O. onites*.) and were cultivated in Ikizce Research and Application Farm of CRIFC, Ankara. The biomass yield of the hybrids was recorded by sustainable cultivation and production and their quality characteristics was also determined. Carvacrol was predominated as a major constituent of the hybrids. While carvacrol is the monoterpene 2-isopropyl-5-methyl phenol, extracted from several natural sources including oregano and thyme, and shows antioxidant, antimicrobial, antihypertensive, immunomodulatory, and anticancer properties, and has also applications in functional food formulations, influenced food quality, and positively affect human health. Both fresh and dried leaves can be used as flavoring. The antioxidant activity of oregano shows a higher activity compared to the same amounts of fresh dill, thyme, sage, and parsley. Regarding the other Medicinal and Aromatic Plants (MAPs) and vegetables, oregano has 42 times more antioxidant activity than apples, 30 times more than potatoes, 12 times more than oranges, and four times more than blueberries (ALAGAWANY et al., 2021; NIKHEEL et al., 2021; ZHENG & WANG, 2001).

Even though previous Origanum studies were mainly conducted in the coastal and mild area of Türkiye, recent cultivation and breeding studies in Central Anatolian conditions were promising regarding the biomass production and their quality characteristics (BAHTIYARCA BAĞDAT et al., 2015). In view of the increasing importance of oregano production in Türkiye, this research investigated the potential production of those original hybrids and also define their quality characteristics. This study is expected not only to fill the knowledge gaps regarding hybrids but also to provide detailed information on selected hybrids' yield and essential oil content for industrial sectors as a source of raw materials.

MATERIALS AND METHODS

Soil structure of experimental site

The soil samples were taken at a depth of 0-20 cm on July 21st, 2021, after the plant materials were harvested from the experimental site and analyzed at the Soil Fertilizer and Water Resources Institute, Ankara. The soil had a clay-loam texture (TS8333) and the soil pH was 7.73 (slightly alkaline). The amount of lime was 30%, categorized in the heavy-lime group. The organic matter rate was 1.97% (insufficient group). The electrical conductivity (EC) of the soil was 0.64 ds/m salt-free (0-2 salt-free). Available Phosphorus (P_2O_5) was determined as 45 kg/ha (insufficient) and potassium (K) as 3060 kg/ha (high). Regarding the microelement analysis of the soil, available iron (Fe) was 3.38 ppm (0.2-4.5 medium), available copper (Cu) 1.33 ppm (> 0.2 sufficient), available zinc (Zn) 0.30 ppm (‹less), and available Manganese (Mn) 3.03 ppm (‹less). The amount of available Zn in the soil was found very low at 0.30 ppm (JACKSON, 1962; HIZALAN & ÜNAL, 1966; LINDSAY & NORWELL, 1978). As it can be understood from the values and classifications of soil properties, the soil in which plant materials were cultivated can be defined as less fertile and insufficient regarding some of the plant nutrients.

Plant materials

The oregano cuttings were provided by Atatürk Horticultural Central Research Institute (Yalova) from a project material (project ID: 104O164) funded by The Scientific and Technological Research Council of Türkiye (TÜBİTAK). Aerial parts (leaves, stems, and inflorescences) of five oregano-hybrids H1 (*O. minutiflorum* x *O. majorana*), H2 (*O. vulgare* x *O. majorana*), H3 (*O. syriacum* x *O. vulgare*), H4 (*O.syriacum* x *O. minutiflorum*) and H5 (*O. onites* x *O. vulgare*) were harvested on July 19th 2021, at the 50% flowering stage, when the essential oil ratio was the highest amount in Central Anatolian climatic conditions (KITIKI, 1996). The samples were dried for three days in a drying cabinet at 35 ºC.

Experimental design

The experiments were established in the Experimental and Production Center of the Central Research Institute of Field Crops (CRIFC), Gölbaşı Ikizce, located at 39613319N and 32671541E. A randomized complete block design technique with three replicates was used with a plant density of 40x30 cm. A plastic mulch layer was covered to control the weed populations and a drip irrigation system was set up under the mulch layer. The observations were taken from a three-year-old Oregano plantation. Each plot size was 5.28 m^2 and the observations were taken from 10 randomly selected plants, from each plot. To compare the yield and quality parameters of the hybrids, *Origanum vulgare* (Acc: Ames 1684, Lot: 79ncai01, USDA) was planted as a reference plant (Control) and evaluated in the experiment. The results were analyzed by analysis of variance and the means were separated by Duncan's Multiple Range Test.

Isolation of the essential oils

Hydrodistillation, a standard extraction method was used to derive essential oils and bioactive compounds from plant materials. EOs were extracted from 100 g dry leaf and flower samples of each species using Neo-Clevenger apparatus by hydrodistillation for three hours, in the Medicinal and Aromatic Plants Unit Laboratory of CRIFC, Ankara, Türkiye. Recirculating, energy/water-saving Chillers (Buchi F-314) were connected to the Neo-Clevenger hydrodistillation apparatus to set the central temperature and cool the system for a better and more sustainable essential oil formation. The vapors condense back to liquid through this cooler and are then collected in the receiving vessel, above hydrosols; while essential oils are lipophilic and soluble in organic solvents, due to their hydrophobic nature and lower density than water. As the oils are surrounded by water, this method can protect essential oils to be extracted at a certain degree without overheating. The main advantage of this extraction technique is its ability to isolate plant materials below 100 °C (El ASBAHANI et al 2009). Neo-Clevenger was cleaned by running the system empty before each analysis. The extracted essential oils were kept in amber vials at -20 °C until they were identified by GC-MS.

Determination of essential oil components

Essential oil components of the species were determined in the Medicinal and Aromatic Plants Laboratory of Bati Akdeniz Agricultural Research Institute. The GC/MS analysis was performed by an Agilent 5975 GC-MSD system. As a column, an Innowax FSC column (having 60m x 0.25mm, 0.25µm film thickness) was used with helium as carrier gas (0.8 mL/min). The essential oil samples were diluted with hexane 1:100 and injected into the column (0.2 µl) with a split ratio of 40:1. At the beginning, the initial oven temperature of the column was 60 °C and then raised to 220 °C with a rate of 4 °C/min and then kept constant at 220 °C for 10 min. The injector temperature was set at 250 °C. The whole analysis period was 60 min for each sample. The mass range was from m/z 35 to 450 using 70 eV electron bombardment ionization. The essential oil components were identified by comparison of their mass spectra with those in the Adams Library, Wiley GC/MS Library, and Mass Finder Library and confirmed by comparison of their relative retention times and their relative retention indices (RRI) (ADAMS, 2007; DAVIES, 1990; JENNINGS & SHIBAMOTO, 1980).

RESULTS AND DISCUSSION

The yield parameters and the biomass production of Hybrids

The means of all parameters as minimum and maximum values, Least Significant Difference (LSD) and the F value, and quality parameters were statistically evaluated in the following observations; in green herb yield (g x plant^{-1}), dry herb yield (g x plant^{-1}), green leaf yield (g x plant^{-1}), dry leaf yield (g x plant^{-1}), herb dry matter (%), leaf dry matter (%), leaf ratio (%) and essential oil ratio (%) as shown in table 1.

The biomass yield of the hybrids is necessary for sustainable cultivation and production. According to table 1. the means plant height of the present hybrids was 51.06 cm, the green herb yield was 280.24 g x plant^{-1}, the dry herb yield was 96.05 g x plant^{-1}, the green leaf yield was 220.23 g x plant^{-1} and the dry leaf yield was 68.36 g x plant^{-1}. The mean herb dry matter was recorded as 33.2% and the leaf dry matter was 24.09%. While the mean leaf ratio was 69.44%. the essential oil ratio was 5.32%. Except for the Essential oil Ratio (5% significant), all the other yield parameters and dry matter ratios were found statistically significant at the level of 1%.

Table 1 - The min.- max and the means of yield parameters, incluiding plant height (cm), green herb yield (g x plant^{-1}), dry herb yield (g x plant^{-1}), green leaf yield (g x plant^{-1}), dry leaf yield (g x plant^{-1}), herb dry matter (%), leaf dry matter (%), leaf ratio (%) and essential oil ratio (%) of Origanum hybrids are given.

	Plant Height	Green Herb Yield	Dry Herb Yield	Green Leaf Yield	Dry Leaf Yield	Herb Dry Matter%	Leaf Dry Matter%	Leaf Ratio	Essential oil Ratio
Min	49.76	235.63	84.66	188.42	47.83	26.56	18.66	58.80	4.20
Max	64.46	317.26	130.35	278.69	86.38	39.86	35.66	80.00	5.96
Means	51.06	280.24	96.05	220.23	68.36	33.32	24.09	69.44	5.32
LSD	4.55	12.74	6.13	8.88	8.98	1.99	2.25	3.85	1.26
F	**	**	**	**	**	**	**	**	*

*:0.05, **: 0.01 statistically significant.

KOSAKOWSKA et al. 2019 cultivated two *Origanum vulgare* var. *hirtum* cultivars in Poland's ecological conditions and recorded 76.49 and 49.44 g of dry mass per plant. Compared to our findings in Ikızce Research and Application farm, the means of the dry herb yield of the hybrids was 96.05 g x plant^{-1}, highly promising.

According to KARIK et al. 2007 research results, conducted in the Marmara region on *O. vulgare* var. *hirtum*, 88-459 g x plant^{-1} green herb and 56-285 g x plant^{-1} dry herb were recorded. The essential oil ratio also ranged between 3.2-6.4%. The components of the samples were; carvacrol 1.88-88.6%, thymol 0.24-82.3%, p-cymene 2.60-16.1%, γ-terpinene 0.46-10.7% and linalool 0.02-1.18%. Among the ten populations regarding their chemotypic evaluation, carvacrol was dominated by six and thymol by four. Two population shows the characteristics of the thymol-carvacrol chemotype. While Marmara Region has a mild climate and a high precipitation regime (500-1000 mm yr^{-1}) compared to Central Anatolian climatic conditions (300-600 mm yr^{-1}), the yield parameters showed a superiority but regarding the essential oil yields and components, the present hybrids had close distributions.

Plant height (cm)

Plant height is one of the major yield parameters and is measured by placing the yardstick at the ground level of the plant to the highest fully expanded leaf, as cm. The highest plant height was recorded from H5 as 64.46 cm almost the same as the control/reference plant (66.60 cm), and this was followed by H1 at 49.76 cm. The means plant height of the experimental was 51.06 cm as shown in figure 1. The fact that *O. vulgare* and *O. onites* have the tendency to grow up vertically has made them the highest plant height hybrid. While the means of the Hybrids were 51.6 cm, it was assumed as productive culture accessions by the recommended plant height of up to 50 cm (SIVICKA et. al. 2011).

KARIK et al. 2007 recorded the plant height in *Origanum vulgare* var. *hirtum* as 50.56 cm (in pre-blooming) and 62.47 cm (in the fully blooming period). FETOUH & MOGHITH (2016) recorded a max. plant height at 28.67 cm in *Origanum vulgare* L. by biofertilizer and compost applicated (15 m^3) plantations. Present findings are very close to KARIK et al. 2007's results and show superiority to FETOUH & MOGHITH (2006)'s.

Green herb yield (g x plant^{-1})

Green herb yield is one of the most considerable criteria in biomass production and is very closely related to the agronomic practices used in their cultivation as well as genetics.

As shown in figure 2. the highest green herb yield was recorded from H4 as 439.93 g and from H5 as 317.26 g per plant. The means of the green herb was 280.24 g and the control was 315.8 g. FETOUH & MOGHITH (2006) recorded the fresh weight yield max. as 91.55 g by biofertilizer and compost applied (15 m^3) in *Origanum vulgare* L. plantation. The green herb yields in the present findings were very promising in H4 (*O. syriacum* x *O. minutiflorum*) and

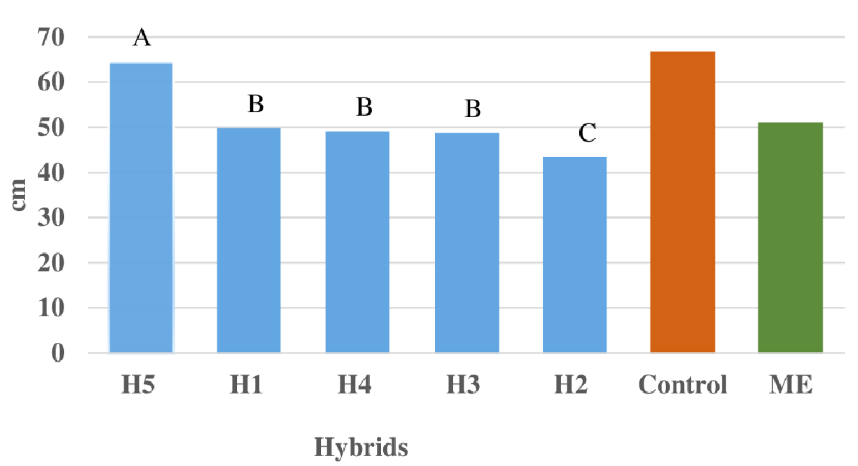

Figure 1 - The plant height (cm) of the hybrids, Control (*Origanum vulgare*) and the means of Experimental (ME).
Letter grouping is based on Duncan's Multiple Range Test.

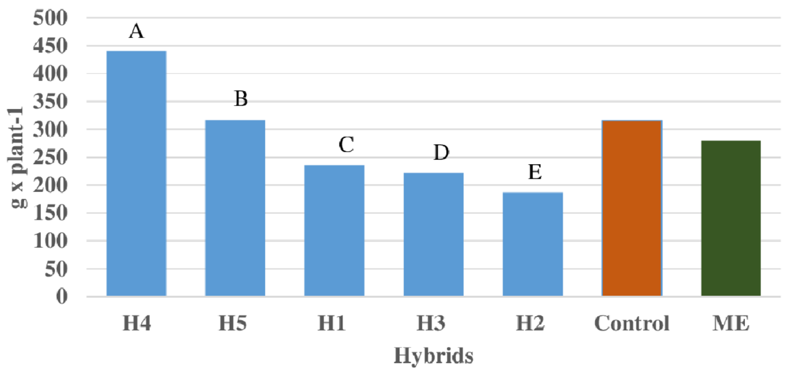

Figure 2 - The green herb yield (g x plant^{-1}) of the hybrids, Control (*Origanum vulgare*) and the means of Experimental (ME). Letter grouping is based on Duncan's Multiple Range Test.

H5 (*O. onites* x *O. vulgare*). Even those prominent species are well adapted to coastal areas of Türkiye, their hybrids recorded a satisfied green herb yield to the Central Anatolian climatic conditions, as well.

Dry herb yield (g x plant^{-1})

Related to green herb yield the highest dry herb yield was recorded from H4 and H5, as follows; 134.74 g and 130.35 g. The means of the dry herb was 96.05 g and the control was 126.95 g x plant^{-1}, as stated in figure 3. NURZYNSKA- WIERDAK (2009), recorded a means of 120.4 g dry weight from the full flowering period of *O. vulgare* L. in successive two years of plantations, in Poland, which is the same species in our present study used as a control by 126.95 g x plant^{-1}. The fresh and dry weight of herbs in NURZYNSKA-WIERDAK (2009)'s research was very close compared to our findings. The photoperiod 12 to 16 hours-light per day, also had a positive impact on the leaf area and a greater total dry weight (MARZI, 1996).

Green leaf yield (g x plant^{-1})

While the leaves are the main site of photosynthesis they are the major determinant used in field studies involving plant growth. The highest green leaf yield was recorded from H2 and H3 as; 278.69g and 244.33 g per plant, respectively, as shown in figure 4. The means of the green leaf yield of the experimental was 220.23g and the Control was recorded as 176.84 g x plant^{-1}.

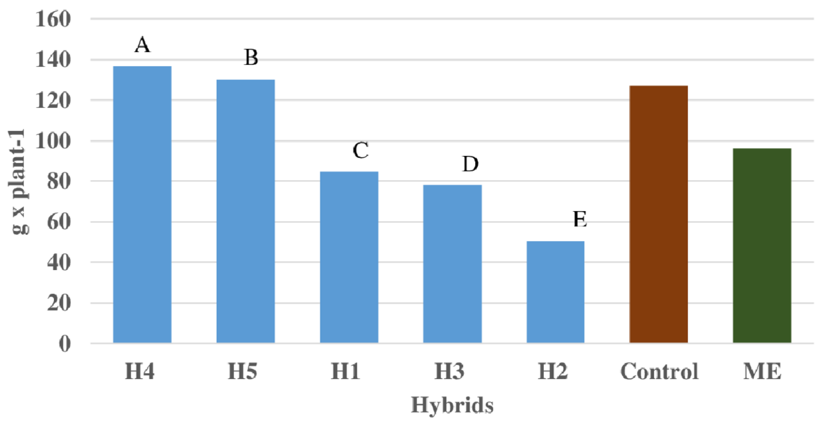

Figure 3 - The dry herb yield (g x plant^{-1}) of the hybrids, Control (*Origanum vulgare*) and the means of Experimental (ME). Letter grouping is based on Duncan's Multiple Range Test.

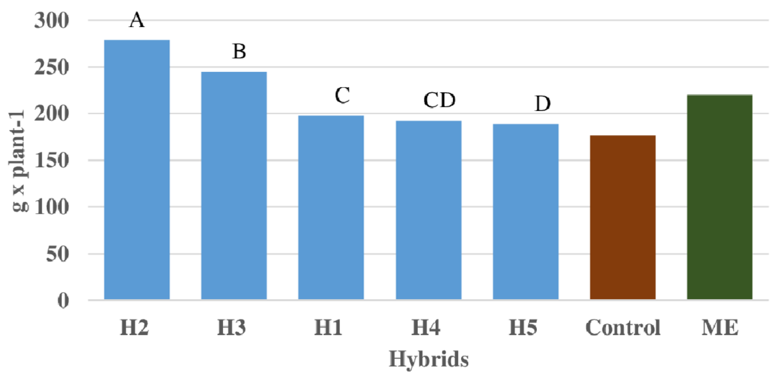

Figure 4 - The green leaf yield (g x plant^{-1}) of the hybrids, Control (*Origanum vulgare*) and the means of Experimental (ME). Letter grouping is based on Duncan's Multiple Range Test.

Dry Leaf Yield (g x plant^{-1})

Oregano leaves stripped from the stems are generated a high value in the markets and high dry leaf yield is an important criterion as a yield component. Related to the green leaf yield the highest dry leaf yield was recorded from H3 and H2 as; 86.38 and 74.21 g x plant^{-1}, respectively. The means of the dry leaf yield of the experimental was 68.36 g and the control was 36.78 g per plant, as shown in figure 5.

Herb dry matter (%)

Medicinal herbs are usually subjected to drying and longtime storage during production, and drying is considered a beneficial way to protect their phytochemical efficiency. Furthermore, it also has the advantage of reducing the cost of the final product, as transportation and storage costs are determined by product weight (CHAN et al. 2009).

The herb dry matter was recorded between 26.56-39.86%, H5, and H2. The means of herb dry matter was 33.32%, as shown in figure 6.

Leaf dry matter (%)

Leaf dry matter content (LDMC, the ratio of leaf dry mass to fresh mass) are important traits in plant ecology because they are associated with many critical aspects of plant growth and survival (GARNIER et al., 2001; SHIPLEY & VU, 2002). It is also an indicator trait of resource-use strategy that also can be used in

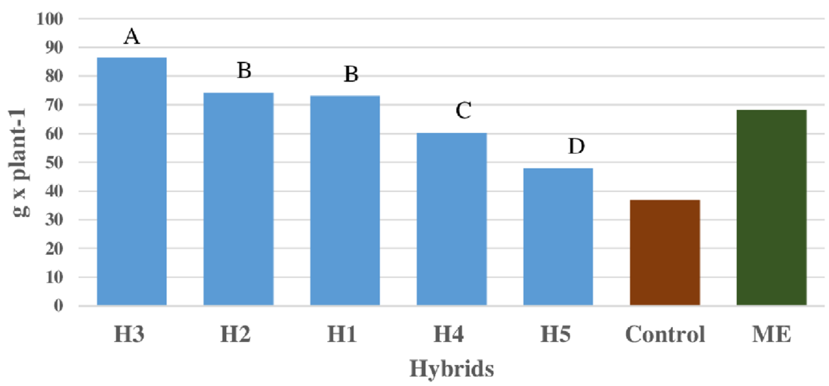

Figure 5 - The dry leaf yield (g x plant^{-1}) of the hybrids, Control (*Origanum vulgare*) and the means of Experimental (ME). Letter grouping is based on Duncan's Multiple Range Test.

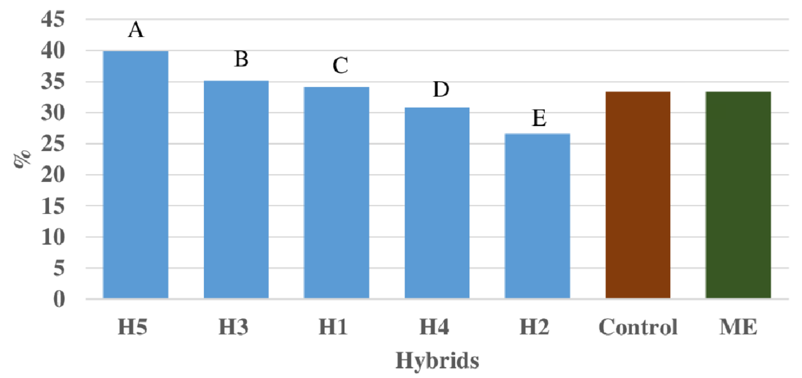

Figure 6 - The herb dry matter (%) of the hybrids, Control (*Origanum vulgare*) and the means of Experimental (ME). Letter grouping is based on Duncan's Multiple Range Test.

the prediction of rapid biomass production (low LDMC species) and in the efficient conservation of nutrients (high LDMC species) (WEIHER, 1999; WESTOBY, 1998).

The highest leaf dry matter was recorded at the experimental from H1 as 35.66%, as shown in figure 7. The means of the leaf dry matter ratio was 24.09% and 20.8% in the control. To maintain the quality of the herbs or, at least, to reduce the negative impact of the storage period, fixing up suitable warehouse conditions is a necessity (MEDIANI et al., 2014).

Leaf ratio (%)

The leaf ratio indicates the efficiency in that the plant uses its leaves to produce plant material. The leaf ratio of the hybrids ranged between 58.8-80.0%, H5, and H1, respectively, as shown in figure 8. The means of the experimental has a 69.44% leaf ratio and the control is 56.0%.

The quality parameters of hybrids

The Essential oil ratio (%) of the hybrids

According to previous oregano studies conducted in the same location, having both local Oregano species and USDA material, the essential oil ratio ranged between 2.0-4.68 % and from CV Carva to 4.8-6.088% (BAHTIYARCA BAĞDAT et al., 2015). Regarding the hybrids, the essential oil ratio ranged between 4.2-5.96%. The means of the essential oil ratio was 5.32% and the control was 5.8%. The highest essential oil was provided from H2 and H3, at 5.96% and 5.77% as shown in figure 9.

The essential oil components of the hybrids

Many studies have been conducted on oregano's essential oils, exploring a large deal of its intraspecific variability. The occurrence of three well-defined chemo-groups is generally acknowledged,

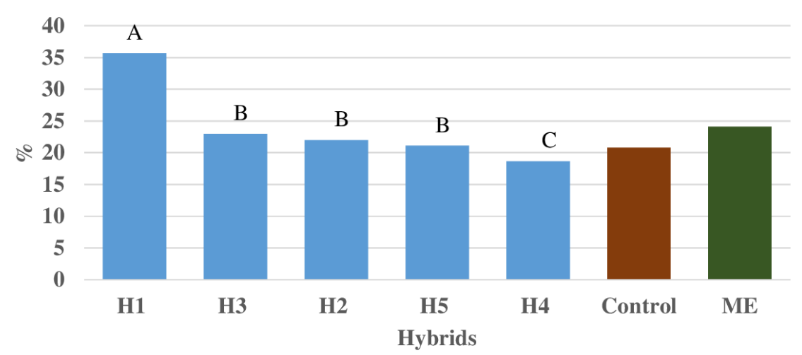

Figure 7 - The leaf dry matter (%) of the hybrids, Control (*Origanumvulgare*), and the means of Experimental (ME). Letter grouping is based on Duncan's Multiple Range Test.

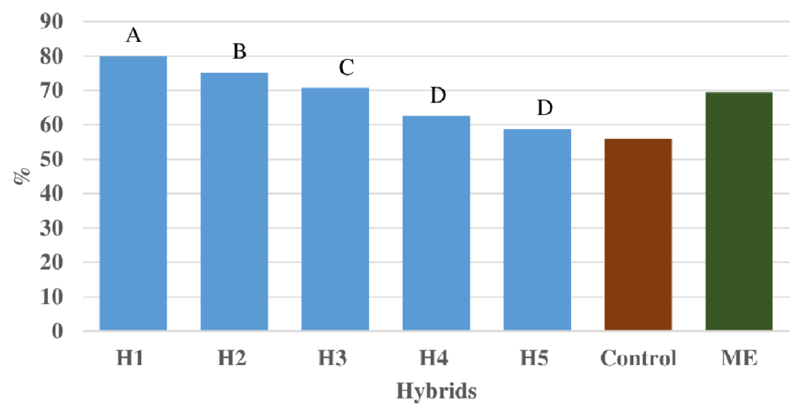

Figure 8 - The leaf ratio (%) of the hybrids, Control (*Origanum vulgare*), and the means of Experimental (ME). Letter grouping is based on Duncan's Multiple Range Test.

namely: (a) the linalool, terpinene-4-ol, and sabinene hydrate group; (b) the carvacrol and/or thymol group; (c) the sesquiterpenes group (KOKKINI, 1996; SKOULA & HARBORNE, 2002). The hybrids showed all the chemical structures of those three chemo groups.

Carvacrol predominated the hybrids at; 77.90% (H1), 61.26% (H3) and 26.99% (H4), 72.09 (H5), and linalool at 45.86% (H2), as shown in figure 10. The other main constituents of the hybrids were linalool, cis sabinene-hydrate, terpinene 4 ol, γ-terpinene, cymene, β-caryophyllene, β-myrcene, α-terpinene, and thymol.

Carvacrol (5-isopropyl-2-methyl phenol) a monoterpenoid phenol, can be classified as a natural multi-target compound and merits attention (SALEHI et al., 2018). Results from in vitro and in vivo studies show that carvacrol possesses a variety of biological and pharmacological properties including antioxidant, antibacterial, antifungal, antiviral, anticancer, anti-inflammatory, antihypertensive, immunomodulatory, hepatoprotective, spasmolytic, and vasorelaxant they can be regarded as promising ingredients for several applications, including the improvement of food quality, food safety and a positive overall impact on human health (SUNTRES et al., 2015; NIKHEEL et al., 2021). KARIK et al (2007) studied a large number of *Origanum vulgare* var. *hirtum* wild accessories collected from the Marmara Region of Türkiye (10 different

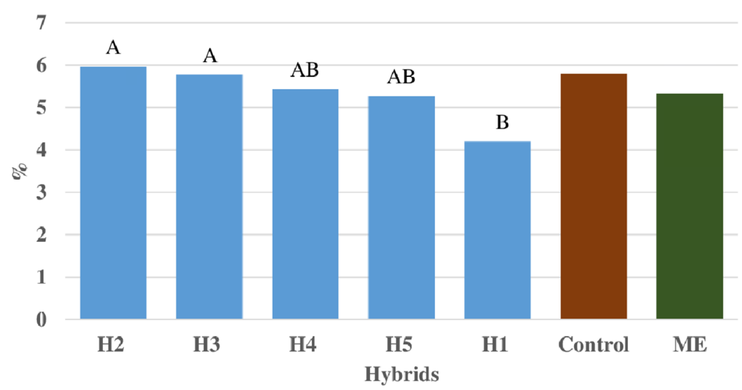

Figure 9 - The essential oil ratio (%) of the hybrids, Control (*Origanum. vulgare*) and the means of Experimental (ME). Letter grouping is based on Duncan's Multiple Range Test.

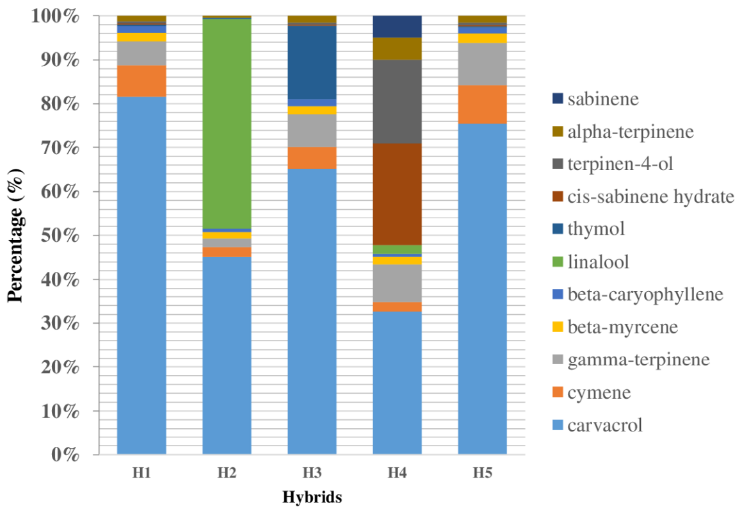

Figure 10 - The distribution of the main essential oil components of H1 (*O. minutiflorum* x *O. majarona*), H2 (*O. vulgare* x *O. majorana*), H3 (*O. syriacum* x *O. vulgare*), H4 (*O.syriacum* x *O.minutiflorum*) and H5 (*O. onites* x *O. vulgare*).

locations in three provinces; Balıkesir, Bursa, and Çanakkale region). The essential oil of the samples ranged between 3.2-6.5%. While thymol dominates between 0.2 and 82.3%, carvacrol was 1.9-88.6%. KOKKINI et al. (2004), isolated the essential oils of *O. vulgare* ssp. *hirtum* and *O. onites* essential oils, collected from three different distinct of Greece. The essential oils of the two taxa were qualitatively similar. Among the ten germplasms, the major essential oil content of *O. vulgare* ssp. *hirtum* was either p-cymene (ranging from 17.7-51.3%) or thymol (30.3-42.8%), while *O. onites* characterized by the preponderance of carvacrol (54.1-71.2%). Different harvest stages changed the biomass yield and chemical constituents of the samples, statistically. The highest biomass production and the quality characteristics of the essential oil were recorded at the full blooming stage (85%), in Yalova ecological conditions. Regarding the present study, the essential oil components of the hybrids were also consistent with the previous studies.

The essential oil components of H1 (O. minutiflorum x O. majorana)

Origanum minutiflorum, an endemic, commonly located in mountainous areas of Isparta province in Türkiye, is announced to be among the most endangered ten species that need to be saved. According to BAYDAR (2005), the optimum harvest date for a high essential oil yield and obtaining the best quality characteristics in *O. minutiflorum*. The essential oil ratios ranged between 1.7 and 4.9% in different development stages and the carvacrol was 60.3 and 92.3%. While the highest carvacrol ratio was determined in the full flowering stage as 92. 3% of the other components were determined as; thymol, p-myrcene, p-cymene, γ-terpinene, α-terpinene, and borneol. BAGCI et al. 2017, compared the differences between the EO compositions of *O. majorana* provided from natural flora and cultivated plantations. Carvacrol was the main component of the dry herbs at 83.46% and 80.33%, respectively. O-cymene and γ-terpinene were the other components, at 2.75 % and 6.50 %.

The major essential oil component of H1 (*O. minutiflorum* x *O. majorana*) was isolated as carvacrol 77.90%. The other components were 6.95% cymene, 5.08% γ-terpinene, 1.86% β-myrcene, 1.46% β-caryophyllene, 1.32% α-thujene and α-terpinene 1.17% as shown in table 2. Figure 11 shows the field images of H1.

The essential oil components of H2 (O. vulgare x O. majorana)

The major essential oil components of H2 were linalool 45.86% and carvacrol 43.22%. Only these two constitute 89.08% of the total

Table 2 - The Essential Oil Components of H1 (*O. minutiflorum* x *O. majorana*).

Peak	R.T.	RI	H1	Pct Total
1	13.16	1030	alpha-pinene	0.84
2	13.30	1033	alpha-thujene	1.32
3	15.09	1076	camphene	0.36
4	19.37	1172	beta-myrcene	1.86
5	20.22	1191	alpha-terpinene	1.17
6	21.07	1210	limonene	0.25
7	23.13	1259	gamma-terpinene	5.08
8	24.23	1285	cymene	6.95
9	31.27	1474	trans-sabinene hydrate	0.67
10	34.10	1560	cis-sabinene hydrate	0.24
11	35.97	1620	terpinen-4-ol	0.48
12	36.20	1628	beta-caryophyllene	1.46
13	38.95	1722	borneol	0.83
14	47.06	2029	caryophyllene oxide	0.22
15	51.17	2201	thymol	0.30
16	52.00	2233	carvacrol	77.90

Figure 11 - Images of H1 (*O. minutiflorum* x *O. majorana*) during field experiments at CRIFC.

component. The other components were; 5.08% γ-terpinene, 1.86 β-myrcene, cymene 2.15%, γ-terpinene 1.84%, β-myrcene 1.38% and carvacrol methyl ether 1.09% as shown in table 3. Figure 12 is also showing the field images of H2 (*O. vulgare* x *O. majorana*).

The essential oil components of H3 (O. syriacum x O. vulgare)

Origanum syriacum considered a native of the Middle East, has two dominant constituents identified as carvacrol (78.4%) and thymol (17.9%), the other components were sabinene hydrate, γ-terpinene, and p-cymene (TOTH et al. 2012; EL-ALAM et al., 2019).

The major essential oil components of H3 were also carvacrol 61.2% and thymol 15.75%. The other components were; γ-terpinene 7.02%, cymene 4.63, β-myrcene 1.74%, β-caryophyllene 1.51%, α-terpinene 1.40%, α-thujene 1.32% and carvacrol methyl ether 1.06% as shown in table 4. Figure 13 shows the field images of H3 (*O. syriacum x O. vulgare*).

The essential oil components of H4 (O. syriacum x O. minutiflorum)

The major essential oil components of H4 were carvacrol 26.99%, cis sabinene hydrate 19.20%, and terpinene-4-ol 15.76%. The other constituents were as follows; γ-terpinene 7.17%, α-terpinene 4.12%, sabinene 4.07%, and trans-sabinene hydrate 3.41%. H4 shows the most unusual distribution among the other hybrids as shown in table 5. Figure 14 shows the field Images of H4 (*O. syriacum* x *O. minutiflorum*).

The essential oil components of H5 (O. onites x O. vulgare)

The major essential oil component of H5 was determined as carvacrol 72.09%. As shown in table 6, the other constituents were; γ-terpinene 9.26%, cymene 8.26%, β-myrcene 2.03, α-thujene 1.48%, and β-caryophyllene 1.26%, respectively. Figure 15 shows the field Images of H5 (*O. onites* x *O. vulgare*).

The essential oil components of Origanum vulgare (Control)

To compare the yield and quality parameters of the Hybrids with a control, *Origanum vulgare* (Acc: Ames 1684, Lot: 79ncai01, USDA) was planted and

Table 3 - The Essential Oil Components of H2 (*O. vulgare* x *O. majorana*).

Peak	R.T.	RI	H2	Pct Total
1	13.16	1030	alpha-pinene	0.32
2	13.30	1033	alpha-thujene	0.62
3	19.37	1172	beta-myrcene	1.38
4	20.22	1191	alpha-terpinene	0.43
5	23.13	1259	gamma-terpinene	1.84
6	24.22	1285	cymene	2.15
7	30.59	1458	1-octen-3-ol	0.39
8	31.27	1474	trans-sabinene hydrate	0.31
9	31.60	1469	trans-linalool oxide	0.25
10	33.88	1558	linalool	45.86
11	35.97	1620	terpinen-4-ol	0.33
12	36.04	1625	carvacrol methyl ether	1.09
13	36.20	1628	beta-caryophyllene	0.71
14	38.95	1722	borneol	0.49
15	39.73	1743	beta-bisabolene	0.31
16	51.16	2201	thymol	0.22
17	51.99	2233	carvacrol	43.22

Figure 12 - Images of H2 (O. vulgare x O. majorana) during field experiments at CRIFC.

Table 4 - The Essential Oil Components of H3 (*O. syriacum* x *O. vulgare*).

Peak	R.T.	RI	H3	Pct Total
1	13.16	1030	alpha-pinene	0.67
2	13.30	1033	alpha-thujene	1.32
3	15.09	1076	camphene	0.27
4	19.37	1172	beta-myrcene	1.74
5	19.56	1178	alpha-phellandrene	0.21
6	20.22	1191	alpha-terpinene	1.40
7	21.07	1210	limonene	0.24
8	23.13	1259	gamma-terpinene	7.02
9	24.22	1285	cymene	4.63
10	30.58	1458	1-octen-3-ol	0.25
11	31.27	1474	trans-sabinene hydrate	0.55
12	34.09	1560	cis-sabinene hydrate	0.19
13	35.97	1620	terpinen-4-ol	0.46
14	36.04	1625	carvacrol methyl ether	1.06
15	36.20	1628	beta-caryophyllene	1.51
16	38.95	1722	borneol	0.67
17	39.73	1749	beta-bisabolene	0.51
18	47.06	2029	caryophyllene oxide	0.19
19	51.17	220	thymol	15.75
20	52.00	223	carvacrol	61.26

Figure 13 - Images of H3 (*O. syriacum* x *O. vulgare*) during field experiments at CRIFC.

Table 5 - The Essential Oil Components of H4 (*O. syriacum* x *O. minutiflorum*).

Peak	R.T.	RI	------------H4------------	PcTotal
1	13.16	1030	alpha-pinene	0.68
2	13.30	1033	alpha-thujene	1.11
3	15.09	1076	camphene	0.26
4	16.95	1120	beta-pinene	0.29
5	17.53	1132	sabinene	4.07
6	19.37	1172	beta-myrcene	1.40
7	20.22	1191	alpha-terpinene	4.12
8	21.07	1210	limonene	0.67
9	21.53	1219	beta-phellandrene	0.81
10	23.13	1259	gamma-terpinene	7.17
11	24.22	1285	cymene	1.76
12	24.72	1297	alpha-terpinolene	1.33
13	28.19	1411	octen-1-ol acetate	0.26
14	31.28	1474	trans-sabinene hydrate	3.41
15	33.85	1558	linalool	1.65
16	34.12	1560	cis-sabinene hydrate	19.20
17	35.43	1596	bornyl acetate	0.20
18	35.98	1620	terpinen-4-ol	15.76
19	36.21	1628	beta-caryophyllene	0.56
20	37.04	1560	cis-dihydrocarvone	0.25
21	38.96	1722	borneol	0.94
22	51.99	2233	carvacrol	26.99

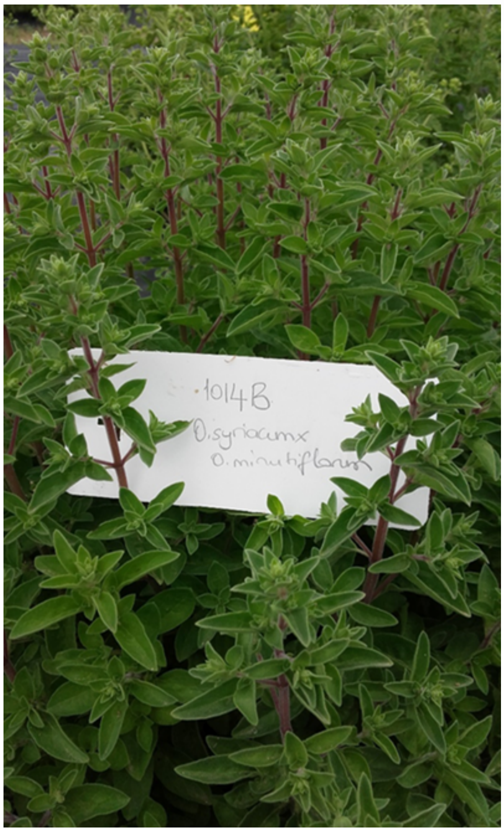

Figure 14 - Images of H4 (*O. syriacum* x *O. minutiflorum*) during field experiments at CRIFC.

evaluated in the experiment. As shown in table 7, the major essential oil component of *Origanum vulgare* (Control) was carvacrol 76.98%, γ-terpinene 9.26%, cymene 8.29%, β-myrcene 2.03%, α-thujene 1.48%, α-terpinene 1.46% and β-caryophyllene 1.26%, respectively. Figure 16 shows the field Images of *O. vulgare* planted as a control in the experimental site.

The composition of *O. vulgare* essential oil from different geographical origins has been characterized by several authors, with carvacrol and thymol as the major components, though the proportions vary widely. Other chemotypes have also been reported as important essential oil components, such as p-cymene, γ-terpinene, caryophyllene, spathulenol, and germacrene-D. The differences in the chemical composition of *O. vulgare* essential oil were recorded to be related to distinct environmental and ecologic conditions, seasonal sampling periods, geographic origins, plant populations, vegetative plant phases, and extraction and quantification methods (BISHT et al. 2009; FIGUEREDO et al. 2005).

CONCLUSION

The present research revealed the cultivation and production potentials of the hybrid oregano species, which are artificially created in greenhouse conditions, and to distinguish their differences or superiorities from their parents. Research results showed that the original hybrids maintained the main essential oil components of their parents and gave a satisfactory biomass production, compared to the local lines. The highest green herb yield was provided from the hybrids of *O. syriacum* x *O. minutiflorum*, as 439.93g and from *O. onites* x *O. vulgare* as 317.26 g x plant^{-1}. The highest green leaf yield was recorded from the hybrid of *O. vulgare* x *O. majorana* and *O. syriacum* x *O. vulgare* as; 278.69 and 244.33 g x plant^{-1}. The leaf ratio of the hybrids ranged between 58.8-80.0%, *O. onites* x *O. vulgare* and *O. minutiflorum* x *O. majorana*, respectively.

The highest essential oil was provided from *O. vulgare* x *O. majorana* and *O. syriacum* x *O. vulgare*, as 5.96% and 5.77%. Carvacrol was the major component of the hybrids at; 77.90% (*O. minutiflorum* x *O. majorana*), 61.26% (*O. syriacum* x *O. vulgare*), and 26.99% (*O. syriacum* x *O. minutiflorum*), 72.09

Table 6 - The Essential Oil Components of H5 (*O. onites* x *O. vulgare*).

Peak	R.T.	RI	-----------H5----------	Pct Total
1	13.16	1030	alpha-pinene	0.82
2	13.31	1033	alpha-thujene	1.48
3	15.09	1076	camphene	0.30
4	19.37	1172	beta-myrcene	2.03
5	20.22	1191	alpha-terpinene	1.46
6	21.07	1210	limonene	0.23
7	23.13	1259	gamma-terpinene	9.26
8	24.23	1285	cymene	8.29
9	31.27	1474	trans-sabinene hydrate	0.57
10	34.10	1560	cis-sabinene hydrate	0.21
11	35.97	1620	terpinen-4-ol	0.54
12	36.20	1628	beta-caryophyllene	1.26
13	38.95	1722	borneol	0.68
14	39.73	1749	beta-bisabolene	0.21
15	47.06	2029	caryophyllene oxide	0.21
16	51.17	2201	thymol	0.30
17	52.00	2233	carvacrol	72.0

Figure 15 - Images of H5 (*O. onites* x *O. vulgare*) during field experiments at CRIFC.

Table 7 - The Essential Oil Components of *O. vulgare* (Control).

Peak	R.T.	RI	*O. vulgare* (Control)	PctTotal
1	13.16	1030	alpha-pinene	0.62
2	13.30	1033	alpha-thujene	1.27
3	15.09	1076	camphene	0.20
4	19.37	1172	beta-myrcene	1.62
5	19.56	1178	alpha-phellandrene	0.20
6	20.22	1191	alpha-terpinene	1.40
7	21.07	1210	limonene	0.22
8	23.13	1259	gamma-terpinene	7.46
9	24.22	1285	cymene	3.82
10	30.58	1458	1-octen-3-ol	0.27
11	31.27	1474	trans-sabinene hydrate	0.52
12	33.84	1558	linalool	0.18
13	34.09	1560	cis-sabinene hydrate	0.18
14	35.97	1620	terpinen-4-ol	0.47
15	36.04	1625	carvacrol methyl ether	1.16
16	36.20	1628	beta-caryophyllene	1.57
17	38.95	1722	borneol	0.53
18	39.73	1743	beta-bisabolene	0.62
19	47.06	2029	caryophyllene oxide	0.19
20	51.16	2201	thymol	0.44
21	52.00	2233	carvacrol	76.9

ORCID: Reyhan BAHTIYARCA BAĞDAT - https://orcid.org/0000-0002-8749-8416.

Figure 16 - Images of *O. vulgare*.

(*O. onites* x *O. vulgare*), and linalool at 45.86% (*O. vulgare* x *O. majorana*). The other components recorded from the hybrids were; cymene, γ-terpinene, β-myrcene, β-caryophyllene, linalool, thymol, cis-sabinene hydrate, terpinene-4-ol, α-terpinene, and sabinene. In addition to the differences in their morphological features, they also differ in aromatic and component aspects. In this view, hybrids could potentially be used in different industrial sectors as sources of high-value phytochemicals.

ACKNOWLEDGMENTS

The author would like to thank Prof. Dr. Mehmet ARSLAN, for interbreeding this hybrid Origanum species and making them available for Oregano breeders. To Ahmet TINMAZ Msc. For providing and sharing the hybrid Oregano species and to Orçun ÇINAR Msc. for identifying the essential oil components chemically.

DECLARATION OF CONFLICT OF INTEREST

The author declares no conflict of interest. This research study complies with research and publishing ethics. The scientific and legal responsibility for manuscripts published in SciELO belongs to the author.

REFERENCES

ALAGAWANY, M. et al. A review on the beneficial effect of thymol on health and production of fish. **Reviews in Aquaculture**, v.13(1), p.632-641, 2021. Available from: <https://onlinelibrary.wiley.com/doi/full/10.1111/raq.12490>. Accessed: Mar. 14, 2023. doi: 10.1111/raq.12490.

BAHTIYARCA BAGDAT, R. et al. Comparison of the yield and quality parameters of certain 'kekik'species grown in central Turkey. **International Journal of Advanced Research in Engineering and Applied Sciences**, v.4(2), p.45-58, 2015. Available from: <https://www.indianjournals.com/ijor.aspx?target=ijor:ijareas&volume=4&issue=2&article=004>. Accessed: Mar. 14, 2023.

BAKHA, M. et al. Genome size and chromosome number for six taxa of Origanum genus from Morocco. **Botany letters**, v.164(4), p.361-370, 2017. Available from: <https://www.tandfonline.com/doi/full/10.1080/23818107.2017.1395766>. Accessed: Mar. 14, 2023. doi: 10.1080/23818107.2017.1395766.

BAYDAR, H. The Effects of Different Harvest Dates on Essential Oil Content and Essential Oil Composition in *Origanum minutiflorum* O. Schwarz et. P.H.Davis. **Akdeniz Üniversitesi Ziraat Fakültesi Dergis**i, v.18(2), p.175-178, 2005. Available from: <https://dergipark.org.tr/tr/pub/akdenizfderg/issue/1580/19604>. Accessed: Jun. 30, 2023.

BAGCI, Y. et al. The Essential Oil Compositions of *Origanum majorana* L. Cultivated in Konya and Collected from Mersin-Turkey. **Indian J of Pharmaceutical Education and Research**, v.51(3), p.463-69, 2017. Available from: <https://www.ijper.org/article/707>. Accessed: Jun. 30, 2023. doi: 10.5530/jiper.51.3s.68.

BISHT, D. et al. Variability in essential oil and bioactive chiral monoterpenoid compositions of Indianoregano (*Origanum vulgare* L.) populations from Northwestern Himalaya and their chemotaxonomy. **Ind Crops Prod.**, v.30, p.422–426, 2009. Available from: <https://www.sciencedirect.com/science/article/pii/S0926669009001277>. Accessed: Mar. 14, 2023. doi: 10.1016/j.indcrop.2009.07.0140.

CHAN, E. W. C. et al. Effects of different drying methods on the antioxidant properties of leaves and tea of ginger species. **Food Chem.**, v.113, p.166–172, 2009. Available from: <https://www.sciencedirect.com/science/article/pii/S0308814608009084>. Accessed: Mar. 14, 2023. doi: 10.1016/j.foodchem.2008.07.090.

DIRMENCI, T. et al. Morphological, cytological, palynological, and molecular evidence on two new hybrids from Turkey: an example of homoploid hybridization in *Origanum* (Lamiaceae). **Phytotaxa**, v.371, p.145-167, 2018. Available from: <https://www.cabdirect.org/cabdirect/abstract/20203483146>. Accessed: Mar. 14, 2023. doi: 10.11646/phytotaxa.371.3.1.

DIRMENCI, T. et al. A rearranged homoploid hybrid species of *Origanum* (Lamiaceae): O.× munzurense Kit Tan & Sorger. **Botany Lett**, v.166, p.153-162, 2019. Available from: <https://www.tandfonline.com/doi/full/10.1080/23818107.2019.1585283>. Accessed: Mar. 14, 2023. doi: 10.1080/23818107.2019.1585283.

EL-ALAM, I. et al. *Origanum syriacum* essential oil chemical polymorphism according to soil type. **Foods**, v.8, p.90, 2019. Available from: <https://www.mdpi.com/2304-8158/8/3/90>. Accessed: Mar. 14, 2023. doi: 10.3390/foods8030090.

FALEIRO, L. et al. Antibacterial and antioxidant activities of essential oils isolated from *Thymbra capitata* L. (Cav.) and *Origanum vulgare* L. **Journal of Agricultural and Food Chemistry**, v.53(21), p.8162-8168, 2005. Available from: <https://pubs.acs.org/doi/full/10.1021/jf0510079>. Accessed: Mar. 14, 2023. doi: 10.1021/jf0510079.

FETOUH, M. I.; MOGHITH, W. et .al. Bio-Production of Origanum vulgare L. Plant underEgyptian Sandy Soil Condition. **Minufiya J. Agric. Res**, v.41 n.2:2, p.443-445, 2016. Available from: <https://www.academia.edu/34100990/BIO_PRODUCTION_OF_ORIGANUM_VULGARE_L_PLANT_UNDER_EGYPTIAN_SANDY_SOIL_CONDITION>. Accessed: Mar. 14, 2023.

FIGUÉRÉDO, G. et al. Studies of Mediterranean Oregano Population IV—Chemical Composition of Essential Oils of Hybrids Origanum x majoricum Cambassedes from France, Origanum x intercedens Rechinger and Origanum x minoanum Davis from Turkey and Crete. **Journal of Essential Oil Research**, v.17(3), p.296-300, 2005. Available from: <https://www.tandfonline.com/doi/abs/10.1080/10412905.2005.9698908>. Accessed: Mar. 14, 2023. doi: 10.1080/10412905.2005.9698908.

GARNİER, E. et al. A standardized protocol for the determination of specific leaf area and leaf dry matter content. **Functional ecology**, p.688-695, 2001. Available from: <https://www.jstor.org/stable/826696>. Accessed: Mar. 14, 2023.

HAMILTON, J. A.; MILLER, J. M. Adaptive introgression as a resource for management and genetic conservation in a changing climate. **Conservation Biology**, v.30, p.33–41, 2016. Available from: <https://conbio.onlinelibrary.wiley.com/doi/full/10.1111/cobi.12574?saml_referrer>. Accessed: Mar. 14, 2023. doi: 10.1111/cobi.12574.

HIZALAN, E.; ÜNAL, H. **Topraklarda önemli kimyasal analizler**, Ankara Üniversitesi Ziraat Fakültesi Yayınları, n.278. Türkiye, 1966. Ankara University Publication Number 278.

JACKSON, M.L. **Soil Chemical Analysis**, Prentice Hall, Inc., Englewood Cliffs, NJ, 1962.

KARIK, U. et al. Effect Of Different Cutting Time On Yield And Quality In İstanbul Kekiği (*Origanum vulgare* L. subsp. *hirtum*) Populations. **Bahçe**, v.36, n.1-2, p.37–48, 2007. Available from: <https://www.cabdirect.org/cabdirect/abstract/20083193491>. Accessed: Mar. 14, 2023.

KITIKI, A. Oregano. Status of cultivation and use of oregano in Turkey. **Proceedings of the IPGRI International Workshop**, Padulosi, S., Ed.; IPGRI: Valenzano, Italy; p.121-131;182, 8-12 May 1996. Available from: <https://books.google.com.tr/oks?id=8gT9nuIlGa0C&printsec=frontcover&hl=tr&source=gbs_ge_summary_r&cad=0#v=onepage&q&f=false>. Accessed: Jun. 30, 2023.

KOKKINI, S. Oregano. Taxonomy, diversity and distribution of Origanum species. **Proceedings of the IPGRI International Workshop**, Padulosi, S., Ed.; IPGRI: Valenzano, Italy; p.2–12;182, 8-12 May 1996. Available from: <https://books.google.com.tr/oks?id=8gT9nuIlGa0C&printsec=frontcover&hl=tr&source=gbs_ge_summary_r&cad=0#v=onepage&q&f=false>. Accessed: Jun. 30, 2023.

KOKKINI, S. et al. Essential Oil Composition of Greek *(Origanum vulgare* ssp. *hirtum*) and Turkish *(O. onites*) Oregano: a Tool for Their Distinction. **J. Essent. Oil Res.**, v.16, p.334-338, July/August 2004. Available from: <https://www.tandfonline.com/doi/abs/10.1080/10412905.2004.9698735>. Accessed: Mar. 30, 2023. doi: 10.1080/10412905.2004.9698735.

KOSAKOWSKA, O. et al. Yield and quality of 'Greek oregano' (*Origanum vulgare* L. subsp. *hirtum*) herb from organic production system in temperate climate. **Industrial Crops and Products**, v.141, p.111782, Dec 2019. Available from: <https://www.sciencedirect.com/science/article/pii/S0926669019307927>. Accessed: Mar. 14, 2023. doi: 10.1016/j.indcrop.2019.111782.

LINDSAY, W. L.; NORVELL, W. Development of a DTPA soil test for zinc, iron, manganese, and copper. **Soil science society of America journal**, v.42, n.3 (3), p.421-428, 1978. Available from: <https://acsess.onlinelibrary.wiley.com/doi/epdf/10.2136/sssaj1978.03615995004200030009x?saml_referrer>. Accessed: Mar. 14, 2023. doi: 10.2136/sssaj1978.03615995004200030009x.

MARZI, V. Agricultural practices for oregano. In: Padulosi S. (ed.) Oregano. Promoting the conservation and use of underutilized and neglected crops. **Proceedings of the IPGRI International Workshop on Oregano**, 8-12 May 1996, CIHEAM, Valenzano (Bari), p.61-68, 182. Available from: <https://books.google.com.tr/oks?id=8gT9nuIlGa0C&printsec=frontcover&hl=tr&source=gbs_ge_summary_r&cad=0#v=onepage&q&f=false>. Accessed: Jun. 30, 2023.

MEDIANI, A. et al. Effects of Different Drying Methods and Storage Time on Free Radical Scavenging Activity and Total Phenolic Content of Cosmos caudatus. **Antioxidants**, v.3, p.358-370, 2014. Available from: <https://www.mdpi.com/2076-3921/3/2/358>. Accessed: Mar. 14, 2023. doi: 10.3390/antiox3020358.

NIKHEEL, B. R. et al. Biological activity of plant-based carvacrol and thymol and their impact on human health and food quality. **Trends in Food Science & Technology**, v.116, n.8, p.733-748, 2021. Available from: <https://www.sciencedirect.com/science/article/pii/S0924224421005100>. Accessed: Mar. 14, 2023. doi: 10.1016/j.tifs.2021.08.023.

NURZYNSKA-WIERDAK, R. Herb yield and chemical composition of common oregano (*Origanum* vulgare L.) essential oil according to the plant's developmental stage. **Herba Polonica**, v.55, n.3 p.55-62. Available from: <https://www.http://herbapolonica.pl/magazines-files/370662-Pages%20from%20Herba_3-6.pdf>. Accessed: Mar. 04, 2023.

SHIPLEY, B.; VU, T. T. Dry matter content as a measure of dry matter concentration in plants and their parts. **New Phytol**, v.153, p.359-364, 2002. Available from: <https://nph.onlinelibrary.wiley.com/doi/full/10.1046/j.0028-646X.2001.00320.x>. Accessed: Mar. 14, 2023. doi: 10.1046/j.0028-646X.2001.00320.x.

SKOULA, M.; HARBORNE, J. B. The Taxonomy and Chemistry of Origanum. In Oregano—**The Genera Origanum and Lippia**, Kintzios, S.E., Ed.; Taylor & Francis: London, UK, 2002; p.67–108.

SUNTRES, Z. E. et al. The bioactivity and toxicological actions of carvacrol. **Crit Rev Food Sci Nutr.**, v.55(3), p.304-18, 2015. Available from: <https://www.tandfonline.com/doi/full/10.1080/10408398.2011.653458>. Accessed: Mar. 14, 2023. doi: 10.1080/10408398.2011.653458.

SIVICKA, L. et al. Fresh and air-dry biomass of oregano (Origanum vulgare L.) accessions. In: **Nordic view to sustainable rural development:** proceedings of the 25th NJF Congress, Nordic Association of Agricultural Scientists, Riga, p.46–51, 16th-18th of June, 2015. Available from: <https://llufb.llu.lv/conference/NJF/NJF_2015_Proceedings_Latvia-46-51.pdf>. Accessed: Jun. 30, 2023.

TOTH, J. et al. Analysis of the Essential Oil Compounds of *Origanum syriacum* L. **Acta Facultatis Pharmaceutical Universitatis Comenianae**, v.59, n.2, p.6–14, 2012. Available from: <https://sciendo.com/article/10.2478/v10219-012-0020-x>. Accessed: Mar. 14, 2023. doi: 10.2478/v10219-012-0020-x.

WEIHER, E. et. al. Challenging Theophrastus: a common core list of plant traits for functional ecology. **J. Veg. Sci.**, v.10, p.609-620, 1999. Available from: <https://www.jstor.org/stable/3237076>. Accessed: Apr. 04, 2023. doi:10.2307/3237076.

WESTOBY, M. A leaf-height-seed (LHS) plant ecology strategy scheme. **Plant Soil**, 199, p.213-227, 1998. Available from. <https://link.springer.com/article/10.1023/A:1004327224729>. Accessed: Apr. 04, 2023. doi:10.1023/A:1004327224729.

ZHENG, W.; WANG, S. Y. Antioxidant activity and phenolic compounds in selected herbs. **Journal of Agricultural and Food Chemistry**, v.49, n.11, p.5165-5170, 2001. Available from: <https://pubs.acs.org/doi/full/10.1021/jf010697n>. Accessed: Mar. 14, 2023. doi: 10.1021/jf010697n.