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ARAŞTIRMA MAKALESİ **RESEARCH ARTICLE**

The effects of essential oils from two different *Satureja hortensis* L. genotypes harvested at different times on weed seed germination

Farklı zamanlarda hasat edilen iki farklı *Satureja hortensis* L. genotiplerinden elde edilen uçucu yağların yabancı ot tohumlarının çimlenmesine etkileri

Ayşe YAŞAR[1], Yücel KARAMAN[1]✉, Nihat TURSUN[1]

[1]*Malatya Turgut Özal University, Faculty of Agriculture, Department of Plant Protection, Malatya, Türkiye.*

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✉Corresponding author/Sorumlu yazar:
Yücel KARAMAN
yucel.karaman@ozal.edu.tr

ABSTRACT

The most important allelopathic effect of essential oils is that they prevent the germination of some plant seeds. In this study, essential oils were obtained from different form periods (beginning of flowering, mid-flowering and end of flowering) of 2 genotypes of *S. hortensis* plant. Subsequently, different doses of essential oils (0.5, 1, 2, 4, 8 and 16 µl petri-1) were used from weeds such as giant amaranth (*Amaranthus palmeri* L.), wild oats (*Avena fatua* L.), purslane (*Portulaca oleracea* L.), wild mustard (*Sinapis arvensis* L.) and cress (*Lepidium sativum* L.), durum wheat (*Triticum durum* L.) and pepper (*Capsicum annuum* L.) seeds from cultivated plants were investigated. According to the results of the study, germination was negatively affected due to the increase in the application doses of essential oils, and the highest effect was determined as 2 µl petri-1 in *A. palmeri* and oleracea seeds, 4 µl petri-1 in *A. fatua* seeds and 8 µl petri-1 in *S. arvensis*. For the effects of essential oil doses, the highest LD_{50} values for the seeds of *A. palmeri*, *P. oleracea*, *A. fatua* and *S. arvensis* were found to be 0.159, 0.189, 1.043 and 3.087, respectively, while the highest LD_{90} values were determined to be 0.547, 0.673, 2.895 and 8.398, respectively. As a result of the study, it was seen that essential oils have a significant bioherbicidal effect on weed seeds and it is thought that this method will make a significant contribution to the alternative control of weeds.

ÖZET

Uçucu yağların allelopatik etkilerinden en önemlisi bazı bitki tohumlarının çimlenmesini engellemesidir. Bu çalışmada *S. hortensis* bitkisinin 2 genotipine ait farklı biçim dönemlerinden (çiçeklenme başlangıcı, çiçeklenme ortası ve çiçeklenme sonu) uçucu yağlar elde edilmiştir. Elde edilen uçucu yağların farklı dozları (0.5, 1, 2, 4, 8 ve 16 µl petri^{-1}) yabancı otlardan dev horozibiği (*Amaranthus palmeri* L.), yabani yulaf (*Avena fatua* L.), semizotu (*Portulaca oleracea* L.), yabani hardal (*Sinapis arvensis* L.) ve kültür bitkilerinden ise tere (*Lepidium sativum* L.), makarnalık buğday (*Triticum durum* L.) ve biber (*Capsicum annuum* L.) tohumlarının çimlenmesine olan etkisi araştırılmıştır. Çalışma sonuçlarına göre: uçucu yağların uygulama dozlarının artışına bağlı olarak çimlenmeler olumsuz yönde etkilenmiş olup *A. palmeri* ve *P. oleracea* tohumlarında en yüksek etki 2 µl petri-^{1}, *A. fatua* tohumlarında 4 µl petri^{-1} ve *S. arvensis*'te ise 8 µl petri^{-1} olarak belirlenmiştir. Uçucu yağ dozlarının yabancı otlardan *A. palmeri*, *P. oleracea*, *A. fatua* ve *S. arvensis* tohumları üzerinde en yüksek LD_{50} değerleri sırasıyla 0.159, 0.189, 1.043 ve 3.087 olarak bulunurken, en yüksek LD_{90} değerleri ise yine sırasıyla 0.547, 0.673,2.895 ve 8.398 olarak hesaplanmıştır. Çalışmanın sonucunda uçucu yağların yabancı ot tohumları üzerinde önemli bir biyoherbisidal etkisinin olduğu görülmüş ve bu yöntemin yabancı otların alternatif mücadelesine önemli bir katkı sağlayacağı düşünülmektedir.

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INTRODUCTION

The cultivation and consumption of plant species, including shrubs, trees, wild herbs, and weeds as food, originated in the early stages of human history. Globally and within our country, wild herbs and weeds have served as significant historical food sources. The utilization and dissemination of renewable plants as food have been crucial considerations for human health (Üstüner, 2022; Üremiş et al., 2023a).

It is estimated that there are approximately 1,000,000 plant species worldwide, with around 500,000 of them described and named thus far. Moreover, approximately 1,000 new plant species are discovered, described, and named each year. Turkey's geographical location at the crossroads of the Mediterranean, Iranian-Turanian, and European-Siberian regions underscores its rich phytogeographical and floristic diversity (Baytop, 1999). As one of the most important centers for phytogeography and floristics, Türkiye is renowned for its vast plant diversity and is classified among the countries with high biodiversity (Üremiş & Uygur, 1999).

While European countries boast around 14,000 plant species, our country is home to approximately 9,900. Notably, about 3,500 of these are endemic, constituting approximately 33% of endemism (Özüdoğru et al., 2011; Tetik et al., 2013; Üremiş et al., 2020). The historical utilization of plant species from early human periods is deeply intertwined with various aspects of social life. Among the myriad reasons for this usage, including nutrition and health, one prominent aspect is their application in medicinal and aromatic contexts. Globally, an estimated 20,000 plant species, including approximately 650-700 in Türkiye, are recognized for their medicinal and aromatic properties. The utilization of plant species in this domain is steadily increasing worldwide (Baytop, 1999).

Plants recognized for their medicinal and aromatic properties serve diverse purposes in contemporary society, including medicine, food, spices, tea, soft drinks, colors, cosmetics, and resins. Ancient civilizations extensively employed these plants for treating diseases, enhancing nutrition, enjoying pleasant scents, and preserving the deceased over many years (Oğan & Cömert, 2022; Üremiş et al., 2023a). Presently, the plant kingdom comprises around 300 families, with one-third of them containing essential oils. Prominent families in this group include Lamiaceae, Pinaceae, Apiaceae, Rutaceae, Myrtaceae, Lauraceae, among others. Herbal extracts and essential oils derived from these plants are known for their antioxidant, antimicrobial, antiseptic, and antibacterial effects. The essential oil content in plants with aromatic and medicinal properties typically ranges from 0.01% to 10% (Yeşilbağ, 2007; Üremiş et al., 2023b).

Certain essential oil groups create a unique surface structure that facilitates the germination of weed seeds or enables plants to grow comfortably while inhibiting unwanted growth. The term 'allelopathy' originates from the Greek words 'allelo' and 'pathy,' signifying the suffering and loss of value of two organisms. Allelopathy is defined as the direct or indirect positive or negative impact on the growth and development of other plants through biochemical substances synthesized by a plant or by substances produced during the biological decomposition of the plant (Rice, 1984; Gholami et al., 2011; Kwiecińska et al., 2011). Allelopathic symptoms from essential oil groups can manifest in various combinations, with the most significant being the inhibition of germination and the reduction of plant growth and development rates (Barney et al., 2005). Chemical substances with allelopathic effects are termed allelochemicals (Telci, 2006) and find applications as fungicides, insecticides, and herbicides. Allelochemicals possessing herbicidal activity are specifically referred to as bio-herbicides (Arıkan & Elibüyük, 2015). *Satureja hortensis* L. (summer savory) typically thrives in impoverished soils. Harvested between June and October, it is dried and employed as a spice in various dishes, earning it the designation of a spice herb (Çetinkaya & Yıldız, 2018). Widely distributed across Anatolia and Bingöl, locals incorporate it into meat dishes and soups (Apuhan & Beyazkaya, 2019). While relatively scarce in the Aegean region, *S. hortensis* naturally flourishes in many cities, belonging to the Lamiaceae family and boasting high essential oil content. Extracts from the plant are recognized for their carminative, diaphoretic, appetite-stimulating, diuretic, stimulant, and potency-enhancing effects (Katar

et al., 2011). Additionally, the species is acknowledged for its antimicrobial properties (Güllüce et al., 2003) and antifungal effects (Bozarı et al., 2017).

It is well-established that the use of both herbicides and pesticides can have adverse effects on both human health and the environment. Consequently, researchers are actively exploring the utilization of essential oil categories and plant extracts for plant protection purposes, offering a potential solution to mitigate these issues (Isman, 2000). The primary objective is to broaden the application of products with natural properties in lieu of those with synthetic characteristics. With an escalating awareness of environmental preservation and a growing acknowledgment of the negative impact of pesticides on human health, there is ongoing research on bio-pesticides as a more biodegradable alternative to synthetic pesticides (Dudai et al., 1993;.Bayat et al., 1996; Dudai et al., 1999;.Salamcı et al., 2007;.Uremis et al., 2008; Kordali et al., 2008; Kordali et al., 2009; Uremis et al., 2017; Cunedioğlu & Uremis,.2018; Yasar et al., 2021).

Preliminary studies were conducted to explore the potential use of essential oils extracted from different genotypes of *Satureja hortensis* L. as bio-herbicides. Subsequently, based on the obtained results, it was decided to proceed with this study. In this research, essential oils extracted from two distinct genotypes and three different harvest times of summer savory (*Satureja hortensis* L.) were employed against common agricultural weeds such as giant amaranth (*Amaranthus palmeri* L.), wild oat (*Avena fatua* L.), common purslane (*Portulaca oleracea* L.), wild mustard (*Sinapis arvensis* L.), along with crops including cress (*Lepidium sativum* L.), durum wheat (*Triticum durum* L.), and pepper (*Capsicum annuum* L.). The study aimed to evaluate the effects on seed germination.

MATERIALS and METHODS

The main material for the experiment comprises essential oils extracted from the plant *Satureja hortensis* L. Weed seeds utilized in the experiments, namely *Amaranthus palmeri* (AMAPA), *Portulaca oleracea* (POROL), *Avena fatua* (AVEFA), and *Sinapis arvensis* (SINAR), were sourced from agricultural lands. Seeds of crops, specifically *Lepidium sativum* (LEPSA) from Istanbul Tohumculuk, *Capsicum annuum* (CPSAN) from Mitofarm Tohumculuk, and *Triticum durum* (TRZDU) from the producer, were also included. The European and Mediterranean Plant Protection Organization (EPPO) database was referenced for the identification of weed and crop seeds (EPPO, 2024).

Cultivation of Satureja hortensis L. plants

To obtain the essential oils utilized in the study, seeds from two genotypes of *S. hortensis* (genotype 1 and genotype 2) were initially sown in pots. Upon reaching a length of 10-15 cm, the plants were transplanted into plots established in the experimental area of Turgut Özal University Malatya, Faculty of Agriculture. Throughout the growing period, the plants received care and were irrigated as needed through a drip irrigation system. Harvesting was performed by cutting the plants at the soil surface during three different stages: at the beginning of flowering (10-20% flowering), in the middle of flowering (50-60% flowering), and at the end of flowering (90-100% flowering). Subsequently, the harvested plants were dried in a shaded and well-ventilated area. Figure 1 depicts the *S. hortensis* genotypes cultivated in the field.

Figure 1. Cultivation of *Satureja hortensis* genotypes in the field
Şekil 1. Satureja hortensis genotiplerinin tarlada yetiştirilmesi

Obtaining essential oils from Satureja hortensis L.

The cultivated *S. hortensis* plants were air-dried in the shade at room temperature (20-25 °C). Once dried, the plants were manually crushed under suitable conditions to facilitate the extraction of essential oil. Subsequently, 100 g of the crushed plant material was weighed and placed in the flask section of the Neo-Clevenger apparatus, and 1 liter of water was added. The Neo-Clevenger device was then set to 200 °C and boiled for 180 minutes. The resulting essential oils were extracted using a micropipette and transferred into glass bottles. These obtained essential oils were stored in a freezer at -18 °C until further use (Önen, 2003; Üremiş et al., 2009).

Setting up germination experiments

The experiments were conducted in the laboratories of the Department of Plant Protection at the Faculty of Agriculture, Malatya Turgut Özal University. Sterilized double-layered filter papers were placed in 1.5 cm high and 9 cm diameter Petri dishes for the study. Prior to the experiment, the seeds intended for use underwent sterilization. In each Petri dish, 25 sterilized seeds were arranged and moistened with 3 ml of distilled water. Given the dormancy of *Sinapis arvensis* seeds, 3 ml of a 2000 ppm gibberellic acid solution was used instead of pure water (Ateş & Üremiş, 2021). Considering the limited solubility of essential oils, 3.5 cm long filter papers were affixed to the inside of the Petri dish lids. Essential oils were then applied onto these papers, the lids were sealed, tightly wrapped with Parafilm, and subsequently placed in a climatic cabinet (Dudai et al., 1993). Various doses of essential oils (0.5, 1, 2, 4, 8, and 16 µl per Petri dish) were applied. As a control, 3 ml of pure water was added to the Petri dishes of the weed seeds employed in the study, *A. palmeri* and *P. oleracea* were stored in a climate chamber at 25 °C, while *S. arvensis* and *A. fatua* were stored in a climate chamber at 15 °C. Among the cultivated plants, *C. annuum* was incubated in a 25°C climate chamber, while T. aestivum and L. sativum were stored in a 15 °C climate chamber. The Petri dishes were opened at the conclusion of the 14^{th} day, and the seeds inside were tallied. Seeds with radicles measuring at least 0.5 cm were considered germinated (Uygur, 1985).

Statistical analysis

The experiments were arranged following a randomized plot design with 4 replications and 2 replicates. Since there was no statistical difference between the averages of the two trials, the combined average of the two trials was calculated and included in the analysis. The obtained values were subjected to ANOVA using the SPSS program. Differences among the averages derived from the trial results were delineated using Duncan's multiple comparison test ($P \leq 0.05$). In conjunction with this test, curve predictions were generated using the probit analysis technique. LD_{50} and LD_{90}, denoting the minimum dose values causing 50% and 90% seed mortality, were separately calculated

and analyzed for each application. The germination inhibition rate formula was computed using equation 1 (Efil & Üremiş, 2019).

Germination Inhibition Rate (%)= [(K– U)/K] x 100 Eq.(1)

K: Germination in control (number)

U: Germination (number) in seeds treated with essential oil

RESULTS and DISCUSSIONS

The effect of essential oil on the germination of weed seeds

Harvesting was carried out at 3 different mowing times [1st mowing (first flowering 10-20%), 2nd mowing (mid-flowering 50-60%) and 3rd mowing (last flowering 90-100%)] from 2 different genotypes of the *Satureja hortensis*. The essential oils were extracted separately from dried plants. The effects of essential oil application on germination rates and lethal doses (LD_{50} and LD_{90}) on seeds were determined in comparison to the control.

When the effect of essential oil on AMAPA seeds on germination was investigated, it was found that the essential oil extracted from *S. hortensis* plant had the least effect (73.8% germination) as a result of treatment with 0.5 µl petri^{-1} in the applications in the 3rd mowing of genotype 2, and the least germination was observed at 2 µl petri^{-1} and later (100% mortality). When the effect of essential oil on POROL seeds on germination was studied, it was found that the essential oil extracted from *S. hortensis* had the least effect (27.6% germination) in the applications in the 3rd mowing of genotype 2 as a result of treatment with 0.5 µl petri^{-1}, and the least germination was observed at 2 µl petri^{-1} and later (100% mortality). When the effect of essential oil applied to AVEFA seeds on germination was investigated, it was found that the essential oil extracted from *S. hortensis* had the least effect (17.5% germination) when applied in the 3rd mowing of genotype 2 as a result of treatment with 0.5 µl petri^{-1}, and the least germination was observed at 8 and 16 µl petri^{-1} (100% mortality). When investigating the effect of essential oil applied to SINAR seeds on germination, it was found that the essential oil from *S. hortensis* had the least effect when applied in the 3rd mowing of genotype 1 and the 1st mowing of genotype 2 (0% germination) as a result of treatment with 0.5 µl petri^{-1}, and the least germination was observed at 16 µl petri^{-1} (100% mortality). When the effect of essential oil applied to LEPSA seeds on germination was examined, it was found that the essential oil extracted from the *S. hortensis* had the least effect in the applications in the first mowing of genotype 1 (0% germination) as a result of treatment with 0.5 µl petri^{-1}, and the least germination was observed at 16 µl petri^{-1} (100% mortality). When the effect of essential oil applied to CPSAN seeds on germination was examined, it was found that the essential oil obtained from the *S. hortensis* had the least effect in the applications in the first mowing of genotype 2 (33% germination) as a result of treatment with 0.5 µl petri^{-1}, and the least germination was observed at 8 µl petri^{-1} (96% mortality). When the effect of the essential oil applied to the TRZDU seeds on germination was examined, it was found that the essential oil extracted from the S. hortensis had the least effect when applied in the 2nd mowing of genotype 1 (0.5% germination) as a result of treatment with 0.5 µl petri^{-1}, and the least germination was observed at 16 µl petri^{-1} (97% mortality) (Figure 2).

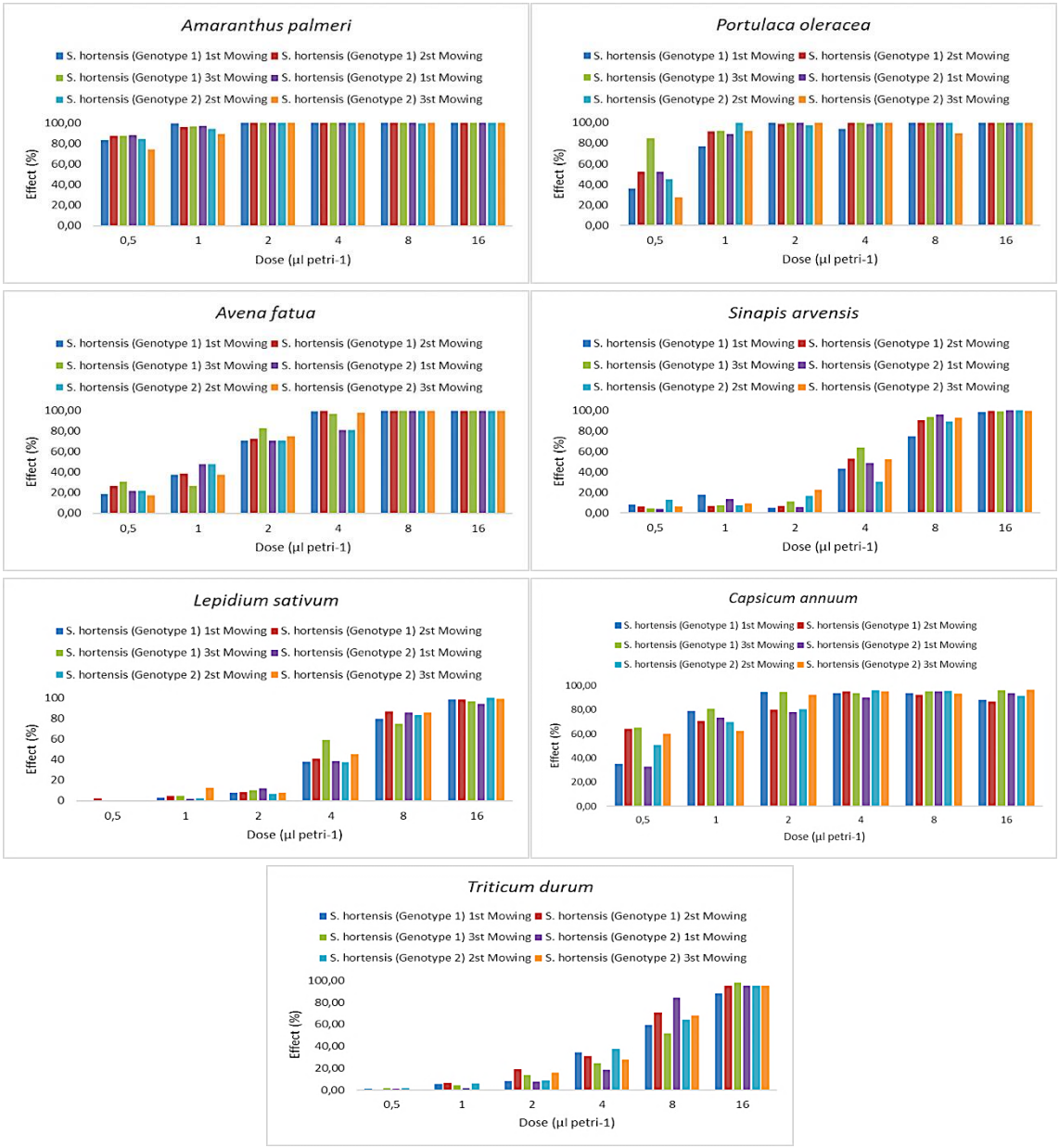

Figure 2. Effect (%) of different doses of essential oil extracted from two different genotypes of *Satureja hortensis* at different times on weed and crop seeds

Şekil 2. Satureja hortensis'in iki farklı genotipinin farklı zamanlarda biçiminden elde edilen uçucu yağın farklı dozlarının yabancı ot ve kültür bitkisi tohumlarına etkisi (%)

When comparing the lethal dose of essential oils applied to AMAPA seeds, the most effective LD_{50} value (0.159 µl petri^{-1}) was obtained in the 2nd mowing of genotype 2, while the most effective LD_{90} value (0.547 µl petri^{-1}) was obtained in the 1st mowing of genotype 2. When comparing the lethal dose of the essential oils applied to POROL seeds, the most effective LD_{50} value (0.189 µl petri^{-1}) was obtained in the 3rd mowing of genotype 1, while the most effective LD_{90} value (0.673 µl petri^{-1}) was obtained in the 3rd mowing of genotype 1. When comparing the lethal dose of essential oils applied to AVEFA seeds, the most effective LD_{50} value (1.043 µl petri^{-1}) was obtained at the 2nd mowing of genotype 1, while the most effective LD_{90} value (2.895 µl petri^{-1}) was obtained at the 3rd mowing of genotype 2. In the lethal dose comparison of essential oils applied on SINAR seeds, the most effective LD_{50} value (3.087 µl petri^{-1}) was obtained from the 2nd mowing of genotype 1, while the most effective LD_{90} value (8.398 µl petri^{-1}) was obtained from the 3rd mowing of genotype 1. In the lethal dose comparison of essential oils applied on

LEPSA seeds, the most effective LD_{50} value (3.866 µl petri^{-1}) was obtained from the 3rd mowing of genotype 2, while the most effective LD_{90} value (9.822 µl petri^{-1}) was obtained from the 2nd mowing of genotype 2. In the lethal dose comparison of essential oils applied on CPSAN seeds, the most effective LD_{50} value (0.122 µl petri^{-1}) was obtained from the 2nd mowing of genotype 1, while the most effective LD_{90} value (2.755 µl petri^{-1}) was obtained from the 3rd mowing of genotype 1. When comparing the lethal dose of the essential oils applied to the TRZDU seeds, the most effective LD_{50} value (4,800 µl petri^{-1}) was obtained in the 2nd mowing of genotype 1, while the most effective LD_{90} value (12,593 µl petri^{-1}) was obtained in the 1st mowing of genotype 2 (Table 1, 2, 3, 4, 5, 6 and 7).

Table 1. LD_{50} and LD_{90} dose values of *Satureja hortensis* essential oil on AMAPA seeds

Çizelge 1. Satureja hortensis uçucu yağının AMAPA tohumları üzerindeki LD_{50} ve LD_{90} doz değerleri

Treatments	LD_{50}	LD_{90}	Df	Slope (±SE)	χ^2	P	Y
Genotype 1 (1st Mowing)	0.332	0.576	4	-1.597 (±3.357)	0.001	1.000	-2.567 -5.361X
Genotype 1 (2nd Mowing)	0.189	0.587	4	-1.854 (±1.403)	0.218	0.994	-1.883 -2.601X
Genotype 1 (3rd Mowing)	0.195	0.579	4	-1.820 (±1.492)	0.158	0.997	-1.925 -2.716X
Genotype 2 (1st Mowing)	0.198	0.547	4	-1.686 (±1.720)	0.079	0.999	-2.041 -2.900X
Genotype 2 (2nd Mowing)	0.159	0.672	4	-2.246 (±0.910)	2.695	0.610	-1.635 -2.044X
Genotype 2 (3rd Mowing)	0.314	0.882	4	-2.779 (±1.030)	0.704	0.951	-1.437 –2.861X

Table 2. LD_{50} and LD_{90} dose values of *Satureja hortensis* essential oil on POROL seeds

Çizelge 2. Satureja hortensis uçucu yağını POROL tohumları üzerindeki LD_{50} ve LD_{90} doz değerleri

Treatments	LD_{50}	LD_{90}	Df	Slope (±SE)	χ^2	P	Y
Genotype 1 (1st Mowing)	0.627	1.240	4	-4.407 (±0.982)	0.729	0.948	-0.877 -4.327X
Genotype 1 (2nd Mowing)	0.491	0.939	4	-3.505 (±1.297)	0.095	0.999	-1.406 -4.545X
Genotype 1 (3rd Mowing)	0.189	0.673	4	-2.107 (±1.106)	0.674	0.954	-1.682 -2.329X
Genotype 2 (1st Mowing)	0.482	0.980	4	-3.511 (±1.183)	0.202	0.995	-1.317 -4.153X
Genotype 2 (2nd Mowing)	0.515	0.820	4	-3.302 (±1.919)	0.865	0.930	-1.826 -6.336X
Genotype 2 (3rd Mowing)	0.617	1.088	4	-4.264 (±1.221)	0.998	0.910	-1.090 -5.205X

Table 3. LD_{50} and LD_{90} dose values of *Satureja hortensis* essential oil on AVEFA seeds

Çizelge 3. Satureja hortensis uçucu yağını AVEFA tohumları üzerindeki LD_{50} ve LD_{90} doz değerleri

Treatments	LD_{50}	LD_{90}	Df	Slope (±SE)	χ^2	P	Y
Genotype 1 (1st Mowing)	1.141	2.985	4	-6.363 (±0.482)	2.393	0.664	0.175 -3.067X
Genotype 1 (2nd Mowing)	1.043	2.965	4	-6.177 (±0.457)	3.808	0.433	0.051 -2.823X
Genotype 1 (3rd Mowing)	1.043	2.975	4	-6.259 (±0.450)	7.626	0.106	0.051 -2.815X
Genotype 2 (1st Mowing)	1.180	3.453	4	-6.544 (±0.420)	2.615	0.624	0.198 -2.748X
Genotype 2 (2nd Mowing)	1.145	4.346	4	-6.395 (±0.346)	2.411	0.661	0.130 -2.212X
Genotype 2 (3rd Mowing)	1.135	2.895	4	-6.366 (±0.495)	1.294	0.862	0.173 -3.151

Table 4. LD_{50} and LD_{90} dose values of *Satureja hortensis* essential oil on SINAR seeds

Çizelge 4. Satureja hortensis uçucu yağını SINAR tohumları üzerindeki LD_{50} ve LD_{90} doz değerleri

Treatments	LD_{50}	LD_{90}	Df	Slope (±SE)	χ^2	P	Y
Genotype 1 (1st Mowing)	4.018	15.926	4	-6.975 (±0.307)	11.207	0.024	1.294 -2.143X
Genotype 1 (2nd Mowing)	3.527	9.856	4	-7.326 (±0.392)	13.751	0.008	1.572 -2.872X
Genotype 1 (3rd Mowing)	3.183	8.398	4	-7.261 (±0.419)	7.809	0.099	1.530 -3.042X
Genotype 2 (1st Mowing)	3.387	9.093	4	-7.242 (±0.413)	13.675	0.008	1.583 -2.988X
Genotype 2 (2nd Mowing)	3.645	13.271	4	-7.191 (±0.318)	19.696	0.001	1.283 -2.284X
Genotype 2 (3rd Mowing)	3.087	9.247	4	-7.253 (±0.371)	5.281	0.260	1.316 -2.689X

Table 5. LD_{50} and LD_{90} dose values of *Satureja hortensis* essential oil on LEPSA seeds

Çizelge 5. Satureja hortensis uçucu yağını LEPSA tohumları üzerindeki LD_{50} ve LD_{90} doz değerleri

Treatments	LD_{50}	LD_{90}	Df	Slope (±SE)	χ^2	P	Y
Genotype 1 (1st Mowing)	4.646	10.688	4	-6.987 (±0.507)	1.621	0.805	2.362 -3.542X
Genotype 1 (2nd Mowing)	4.136	10.457	4	-7.417 (±0.429)	7.553	0.109	1.961 -3.181X
Genotype 1 (3rd Mowing)	4.135	11.291	4	-7.359 (±0.399)	2.766	0.598	1.811 -2.937X
Genotype 2 (1st Mowing)	4.549	10.975	4	-7.117 (±0.471)	1.109	0.893	2.204 -3.351X
Genotype 2 (2nd Mowing)	4.500	9.822	4	-6.913 (±0.547)	5.975	0.201	2.470 -3.781X
Genotype 2 (3rd Mowing)	3.866	10.484	4	-7.491 (±0.395)	7.704	0.103	1.737 -2.958X

Table 6. LD_{50} and LD_{90} dose values of *Satureja hortensis* essential oil on CPSAN seeds

Çizelge 6. Satureja hortensis uçucu yağının CPSAN tohumları üzerindeki LD_{50} ve LD_{90} doz değerleri

Treatments	LD_{50}	LD_{90}	Df	Slope (±SE)	χ^2	P	Y
Genotype 1 (1st Mowing)	0.367	4.914	4	-3.715 (±0.306)	11.427	0.022	-0.495 -1.137X
Genotype 1 (2nd Mowing)	0.122	8.202	4	-2.443 (±0.287)	2.697	0.610	-0.641 -0.701X
Genotype 1 (3rd Mowing)	0.146	2.755	4	-2.868 (±0.351)	1.541	0.819	-0.839 -1.005X
Genotype 2 (1st Mowing)	0.612	4.966	4	-4.333 (±0.325)	3.400	0.493	-0.301 -1.409X
Genotype 2 (2nd Mowing)	0.371	4.777	4	-3.649 (±0.316)	3.137	0.535	-0.498 -1.154X
Genotype 2 (3rd Mowing)	0.332	3.653	4	-3.592 (±0.342)	2.968	0.563	-0.589 -1.230X

Table 7. LD_{50} and LD_{90} dose values of *Satureja hortensis* essential oil on TRZDU seeds

Çizelge 7. Satureja hortensis uçucu yağının TRZDU tohumları üzerindeki LD_{50} ve LD_{90} doz değerleri

Treatments	LD_{50}	LD_{90}	Df	Slope (±SE)	χ^2	P	Y
Genotype 1 (1st Mowing)	5.897	20.464	4	-6.887 (±0.344)	1.681	0.794	1.828 -2.372X
Genotype 1 (2nd Mowing)	4.800	15.060	4	-7.168 (±0.360)	2.277	0.685	1.758 -2.581X
Genotype 1 (3rd Mowing)	5.873	19.248	4	-6.902 (±0.360)	7.295	0.121	1.911 -2.486X
Genotype 2 (1st Mowing)	5.198	12.593	4	-7.163 (±0.466)	20.529	0.000	2.387 -3.335X
Genotype 2 (2nd Mowing)	5.129	16.427	4	-7.153 (±0.354)	3.24	0.518	1800 - 2.535X
Genotype 2 (3rd Mowing)	5.366	14.254	4	-6.906 (±0.437)	2.731	0.604	2.204 -3.021X

Plants, like many other living organisms, synthesize various compounds to protect themselves. The compounds they synthesize are transformed into new compounds in their environment (Charles et al., 1991; Üremiş et al., 2023a). The most important compounds synthesized for self-protection and defense are essential oils (Tworkoski, 2002; Soylu et al., 2006; Dragoeva et al., 2014). Essential oils have been reported to kill weeds, microorganisms and nematodes by gas effect and contact method (Marino et al., 2001; Busatta et al., 2007; Karabörklü, 2008; Üremiş et al., 2023b). It is reported that essential oils penetrate into the cell through the cell wall of the plant, arrest some processes within the cell and disrupt the structure of the cell wall, thereby stopping germination and causing death (Dudai et al., 1999; Chang et al.,.2001; Marino et al., 2001; Ulte et al., 2002; Üremiş et al., 2023a). Recently, essential oils have been favored as an alternative to commercially available synthetic chemicals because of these properties. Essential oils are known as bio-herbicides, that are derived from plants and do not pose any danger to human health and have no side effects (Arslan & Üremiş, 2015; Pinto, et al., 2006). Due to their specific properties, these essential oils are not only used in the cosmetic, perfume and pharmaceutical industries, but studies are also being conducted to make them alternatives to synthetic compounds (Arslan & Üremiş, 2015; Üremiş et al., 2023b). In this study, essential oils extracted from the biologically active *S. hortensis* were used against weeds. By applying them to the seeds of *A. palmeri*, *P. oleracea*, *A. fatua* and *S. arvensis* as well as to the seeds of the cultivated plants *L. sativum*, *C. annuum* and *T. durum*, important data were obtained on their usability as a bio-herbicide.

Studies have shown that the effect of essential oils increases in parallel with the increase in dose (Mukhopadhyay et al., 1995; Üremiş et al., 2009; Üremiş et al., 2011; Cünedioğlu & Üremiş, 2018; Şahin et al., 2013; Yazlık, 2014) and this situation is similar to our study (in general, the effect is 100% at 8 and 16 µl petri^{-1}). It can be observed that *A. palmeri* and *P. oleracea* are more resistant to the essential oils used in the study than *A. fatua* and *S. arvensis*. Luciana et al. (2003) applied the essential oil extracted from the plant *Satureja montana* to the seeds of *P. oleracea*, *C. album* and *Echinochloa crus-galli* and found that the essential oil had an inhibitory effect on the germination of these weed seeds. These results are similar to the results of our study. Cünedioğlu & Üremiş (2018) reported in their study that the essential oil from the *O. minutiflorum* at the lowest dose of 2 µl petri^{-1} and the highest dose of 32 µl petri^{-1} reduced the seeds of the weed *A. retroflexus* by 73.3% and the seeds of *S. arvensis* by 73.3%. They found that the effect was 100%. In our study, the effect of the essential oil extracted from the *S. hortensis* plant was determined at the lowest dose of 0.5 µl petri^{-1}, while the other doses (2, 4, 8 and 16 µl petri^{-1}) showed a 100% effect on the seeds of *A. palmeri*. Barney et al. (2005) state that essential oils extracted from plants prevent seed germination and negatively affect their development. They also report that some essential oils may have a reduced effect on the seeds, which is due to the constituents of the essential oil (Çetintaş et al., 2006). Karaman et al. (2021) found that the effect of applications with a dose of 0.5 µl petri^{-1} and above was quite high in *A. palmeri* and *A. albus*,

but this effect was achieved in *S. arvensis* and *A. fatua* with a dose of 8 and 16 µl petri-1. Essential oils from *Melissa officinalis, Thymus vulgaris, Lavandula angustifolia* and *Salvia officinalis* were found to inhibit seed germination and plant development when applied to *Avena sterilis* seeds (Üremiş et al., 2009). Similar results were observed with the essential oil of *Satureja hortensis* on the seeds of *Avena fatua*. In the study, the effect of *S. hortensis* essential oil on the germination of wheat seeds from cultivated plants was observed at the lowest dose of 0.5 µl petri^{-1} (99.5% germination), while the highest effect was observed at a dose of 16 µl petri^{-1} (2% germination). Cünedioğlu & Üremiş (2018) reported that among the crops to which *Rosmarinus officinalis* essential oil was applied, wheat seeds had the lowest germination rate at 0.5%. When essential oils of *Origanum vulgare, Melissa officinalis, Hyssopus officinalis, Ocimum basilicum, Salvia officinalis, Lavandula angustifolia, Thymus vulgaris* and *Majorana hortensis* were applied to seeds of *Lepidium sativum* L., they were found to have a proportional inhibitory effect on germination depending on the doses (Arminante et al., 2006). It is observed that the germination of *S. hortensis* essential oil on *Lepidium sativum* seeds decreases with increasing dose. Karaman et al., (2021) found in their study that *Mentha pulegium* essential oil was applied to the seeds of *Capsicum annuum* and *Triticum aestivum* and that the least effect was observed at a dose of 0.5 µl petri^{-1}, while the greatest effect was recorded at a dose of 16 µl petri^{-1}. In paprika, it increased significantly at a dose of 2 µl petri^{-1}, while this was the case for wheat when 8 and 16 µl petri^{-1} were applied. In our study, the lowest effect of *S. hortensis* essential oil on pepper seeds was obtained at a dose of 0.5 µl petri^{-1}, while the highest effect was observed at a dose of 16 µl petri^{-1}. According to Karaman et al. (2021), although the effects of the different doses are similar, there are differences between the application doses. The reason for this is that the essential oils used are extracted from different plants. For example, it was found that the essential oils extracted from the plant *Satureja hortensis* significantly suppressed the germination of weed seeds depending on the dose increase. The effect on pepper seeds was found to increase after certain doses. The high effect of the essential oil at lower doses on *A. palmeri*, an invasive weed that is a problem in agricultural areas, indicates that allelopathic studies will come to the fore as an alternative control method. In these cases, the cultivation of *S. hortensis*, a medicinal and aromatic plant, as a by-product or as a rotation crop in areas where peppers are grown, could be an alternative solution for weed control.

In conclusion, it was observed that low doses of *S. hortensis* essential oil used in the study had a significant impact on inhibiting the germination of weed seeds. The 0.5 µl per Petri dish dose of the essential oil, employed in the experiment, displayed a minimal inhibition of *C. annuum* seed germination, a summer crop plant, but significantly inhibited the germination of *A. palmeri* seeds, a summer weed. Simultaneously, the doses of 2 and 4 µl per Petri dish minimally inhibited the germination of *T. durum* seeds, while markedly inhibiting the germination of *A. fatua* seeds, a winter weed problematic in wheat fields. Consequently, it was noted that higher doses of the obtained essential oil were required to hinder the germination of cultivated plant seeds, while lower doses sufficed to achieve this effect on weeds.

As a result, cultivating the *S. hortensis* plant, recognized for its medicinal and aromatic properties and commonly utilized in the pharmaceutical industry, as an intermediate crop or incorporating it into crop rotation in areas designated for pepper and wheat cultivation is proposed as a potential solution. However, considering the uncertainty regarding its performance under field conditions, it is recommended to further research on this subject. While the results obtained under laboratory conditions are promising, it is crucial to explore new studies considering innovative application techniques and various formulation types. This is particularly necessary due to the lack of selectivity associated with essential oils and the challenges in applying them in greenhouse and field conditions. The essential oil derived from *S. hortensis* demonstrates a potential bioherbicidal effect against weeds. The data from this study envision the formulation and utilization of *S. hortensis* essential oil as a natural bio-herbicide, aiming to hinder the germination or growth of weeds. These findings are anticipated to provide valuable insights for research endeavors in the coming years.

STATEMENT OF CONFLICT OF INTEREST

The author(s) declare no conflict of interest for this study.

AUTHOR'S CONTRIBUTIONS

The authors declare that they have contributed equally to the article.

STATEMENT OF ETHICS CONSENT

Ethical approval is not applicable, because this article does not contain any studies with human or animal subjects.

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