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ARAŞTIRMA MAKALESİ **RESEARCH ARTICLE**

Agronomic Comparisons of Herbicides with Different Active Ingredients and Mechanical Hoeing for Weed Control in Oleic and Linoleic Type Sunflower (*Helianthus annuus* L.) Hybrids*

Oleik ve Linoleik Ayçiçeği Çeşitlerinde Yabancı Ot Mücadelesi İçin Uygulanan Farklı Aktif Madde İçerikli Herbisitler ve Mekanik Çapalama Yönteminin Agronomik Açıdan Karşılaştırılması

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Abstract

Weeds cause serious yield losses in sunflower production. The most common methods for weed control are herbicide application and mechanical hoeing. The objective of this study was to determine the effects of five traditional herbicides containing different active ingredients compared with mechanical hoeing for weed control on seed yield components, seed oil content, and fatty acid composition in sunflower. Field experiments were conducted in the sunflower growing seasons of 2014 and 2015 on farmer fields in Karamusul village of Lüleburgaz, Kırklareli, located in the Northwest of Turkey (40°24' N, 27021 E and elevation 46 m). Pre-plant herbicide Bonoflan WG with benfluralin, pre-emergence herbicide Stomp®Extra with pendimethalin, and post-emergence herbicides Challenge600 with aclonifen and Targa Super with quizalofop-p-ethyl active were applied on non-Clearfield sunflower hybrids (P64LL05–Linoleic and P64H34–High oleic) while post-emergence herbicide Intervix®Pro with imazamox was applied on Clearfield hybrids (LG5542CL-Linoleic and Colombi–High oleic). In the results, the year effects were statistically significant on plant height, head diameter, number of days from planting to 50% flowering, and percentage of stearic acid of Clearfield cultivars while it was significant on plant height, head diameter, stem diameter, 1000 seed weight, number of days from planting to 50% flowering, seed yield, seed oil content, percentage of oleic and linoleic acids of non-Clearfield cultivars. The effect of genotype was significant for all seed yield and oil components except seed weight and seed yield for both groups' cultivars. Intervix®Pro caused significant decreases in plant height, stem diameter, and percentage of stearic acid. Stomp®Extra decreased the number of days from planting to 50% flowering. Challenge 600 had a negative effect on the seed oil content of P64H34 in 2015. There was no significant difference between herbicide applications and mechanical hoeing for seed yields except for increasing seed yield of P64H34 by Bonaflan WG in 2015. For all herbicide applications, residue in seeds was not exceeded international acceptable limits. According to the results, herbicides especially post-emergence applications under stress conditions can adversely affect agronomic yield and seed oil components in sunflower.

Keywords: *Helianthus annuus*, Herbicide, Hoeing, Seed yield, Oil content, Weed control.

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Öz

Yabancı otlar ayçiçeğinde ciddi verim kayıpları oluşturmaktadır. Yabancı otlarla mücadelede en çok kullanılan yöntemler herbisit uygulaması ve mekanik aletlerle çapalamadır. Bu çalışmanın amacı farklı aktif madde içeriğine sahip 5 ticari herbisit ile mekanik aletlerle yapılan çapalamanın ayçiçeğinin tane verimi unsurları, tane yağ içeriği ve yağ asitleri kompozisyonlarına etkilerini belirlemektir. Tarla denemeleri 2014 ve 2015 yıllarını kapsayan iki ayçiçeği yetiştirme mevsiminde Türkiye’nin kuzey batısında yer alan Kırklareli ilinin Lüleburgaz ilçesine bağlı Karamusul Köyünde (Enlem: 40°24’ K, Boylam:27.021 D ve Rakım:46 m) çifti arazisinde yürütülmüştür. Araştırmada: çıkış sonrası kullanılan imazamox etken maddeli ticari Intervix®Pro herbisiti genetik Clearfield ayçiçeği hibriti çeşitlerine (LG5542CL-yüksek linoleik ve Colombi–yüksek oleik) uygulanmıştır. Ekim öncesi herbisitlerden benfluralin etken maddeli Bonoflan WG, çıkış öncesi herbisitlerden pendimethalin etken maddeli Stomp®Extra, çıkış sonrası kullanılan herbisitlerden aclonifen etken maddeli Challenge600 ve quizalofop-p-ethyl etken maddeli Targa Super ticari herbisitleri ise Clearfield geni taşımayan ayçiçeği hibrit çeşitlerine (P64LL05–yüksek linoleik ve P64H34–yüksek oleik) uygulanmıştır. Araştırma sonuçlarında; yıl faktörü Clearfield olmayan çeşitlerin bitki boyu, tabla çapı, sap çapı, 1000 tohum ağırlığı, ekimden %50 çiçeklenmeye kadar olan gün sayısı, tane verimi, tane yağ içeriği, oleik ve yağ asitleri içeriğine istatistiki önemli etkiye sahip olurken, Clearfield çeşitlerinde ise bu faktörün bitki boyu, tabla çapı, ekimden çiçeklenmeye kadar olan gün sayısı ve stearik asit üzerine olan etkileri istatistik anlamda önemli bulunmuştur. Genotip ise her iki grup için de tane verimi ve tane ağırlığı haricinde diğer ölçülen tüm verim ve yağ unsurları üzerinde istatistiki anlamda önemli etkiye sahip olmuştur. Intervix®Pro herbisitinin ayçiçeğinin bitki boyunda, sap çapında ve tohumlardaki yağın stearik asit içeriğinde düşüşlere neden olduğu belirlenmiştir. Stomp®Extra herbisiti ekimden %50 çiçeklenmeye kadar olan gün sayısını azaltarak erken çiçeklenmeye neden olmuştur. Challenge 600 ticari herbisiti ise 2015 yılında P64H34 çeşidinin tanelerindeki yağ oranının düşürmüştür. Tane verimi açısından Bonaflan WG hariç, herbisit uygulamaları ile mekanik çapalama arasında istatistiki açıdan önemli fark bulunamamıştır. Bonoflan WG ticari herbisitinin ise 2015 yılında P64H34 çeşidinde tane verimi üzerinde istatistiki açıdan önemli ve olumlu etkide bulunduğu belirlenmiştir. Tüm herbisit uygulamalarından hasatta elde edilen tane ürünlerinde yapılan pestisit analizlerinde limiti geçen bir değer bulunamamıştır. Araştırma sonuçlarına göre; herbisitler, stres koşullarında özellikle çıkış sonrası uygulamalarda ayçiçeğinin agronomik verim ve yağ unsurlarını olumsuz etkileyebilmektedir.

Anahtar Kelimeler: Çapalama, *Helianthus annuus*, Herbisit, Tohum verimi, Yabancı ot kontrolü, Yağ içeriği.

1. Introduction

Sunflower (*Helianthus annuus*) is one of the most important oilseeds with an annual 21.15 million metric tons of vegetable oil and 22.56 million tons of meal production in the world (USDA, 2021). Weeds are major yield-limiting factors and continue to pose a huge challenge for the production of sunflower. Sunflower is more vulnerable to weed competition during the first several weeks of growth than many other row crops (Soares et al., 2019; Kanatas, 2020). In the later growth stages, sunflower has an allelopathic potential to use for controlling weeds (Jabran, 2017). Crop yield decreases depending on weed population and sunflower growth stage are ranged from 10% to 70% (Delchev and Georgiev, 2015; Kanatas, 2020). Weed control in crop production is very important. The most common preferable method by the farmers for weeds is a chemical application which is economical in short term and has faster results to get rid of weeds. Pesticide use has become inevitable in agriculture and increased several folds during the last four decades.

Overuse of these chemicals has severe effects on the environment that may lead to immediate and long-term effects (Bhandari, 2014; Mingo, et al., 2016; Ferrante and Fearnside, 2020). Numerous studies have been carried out on the effects of pesticides on the environment and human health. Extensive or inappropriate use of pesticides by farmers can lead to the contamination of various ecosystems. Widespread distribution of pesticides is also known to cause problems with the apiculture and surface waters (Lari et al., 2014: Scholz-Starke et al., 2018; Wang et al., 2021). Since bees are the most important pollinators of crops, the use of pesticides can considerably reduce the yield of cross-pollinated crops (Önemli, 2005a; Önemli, 2005b; Barganska et al., 2014; Jumarie et al., 2017). The persistence of pesticides in soil and their residual effects on sequential crops have been reported by many researchers (Cassino et al., 2017; Çebi, 2018). Severe effects of herbicides have also been announced in agency reports of International Organizations (EFSA, 2014; FAO, 2019).

Herbicides also cause high phytotoxicity and damage to crops or non-target plants due to the wrong usage with technical implementation (Suryavanshi et al., 2015; Hasanuzzaman et al., 2020).

Mechanical weeding used alone or with herbicides in integrated weed control strategies also plays an important role in weed control (Pannacci and Tei, 2014). Although it is expensive, tedious, and time-consuming and also may cause root injury (El-Metwally and El-Wakeel, 2019) it has a minimum negative effect on human health and the environment according to chemical weed control.

The most of part of previous researches have been on the effectivity of herbicides for weed control in weed-crop competition (Elezovic et al., 2012; Selvakumar, 2018; Nicolae et al., 2019). Crop productivity in some of these researches was also measured in order to confirm the importance of successful weed control (Knezevic et al., 2013; Petcu and Ciontu, 2014; Suryavanshi et al., 2015; Jursík et al., 2020). A few studies have been conducted to determine the effects of herbicides on the seed yield, and some physiological and agronomical traits of sunflower under weed competition (Tawaha et al., 2002; Simic et al., 2011; Bharati et al., 2020; Mohapatra et al., 2020).

On the other hand, there is very low availability of data on comparisons between herbicide and mechanical hoeing weed control for the effects on the seed yield, seed oil content, fatty acids, and yield components such as flowering time, seed weight, plant height and head diameter in sunflower. The aim of the present study was to investigate the effect of five herbicides including different active ingredients applicated with respect to labeled dose and time making comparisons with hoeing weed control on seed yield, some yield components, seed oil content, and oil fatty acid profiles of two oleic and two linoleic sunflower hybrids. In addition, the herbicide residue of seeds for each application was determined whether it has exceeded the international limits.

2. Materials and Methods

2.1. Research area, soil properties, and meteorological data

Field experiments were conducted in two sunflower growing seasons including 2014 and 2015 on farmer fields in Karamusul village of Lüleburgaz, Kırklareli, located in the Northwest of Turkey (40°24’ N, 27.021 E and elevation 46 m). Kırklareli is one of the main sunflower-growing regions of Turkey. Some soil properties of experimental areas are given in *Table 1*. Soil properties in both years were similar. Soils of 2-yr field experiments were clay loam texture, neutral pH, and poor organic matter.

Table 1. Soil properties of experimental fields in 2014 and 2015

Year	SOM (%)	PH	Lime (%)	Salt (%)	N (%)	P_2O_5 ppm	K ppm	Ca ppm	Fe ppm	Mn ppm	Mg ppm
2014	1.92	6.7	0.57	0.07	0.08	14.28	212	4225	12.13	15.16	414
2015	1.88	6.8	0.68	0.08	0.09	14.36	228	4313	12.48	15.38	432

Table 2 shows some meteorological data during two sunflower growing seasons. In the second year, the beginning of the vegetative period and after R6 (flowering complete, ray flowers wilting) was very dry although all other vegetative and reproductive growth periods were very rainy in the first year.

Table 2. Some climatic data during growing periods of sunflower in 2014 and 2015.

Month	Rainfall (mm)		Relative humidity (%)		Temperature (^{0}C)	
	2014	2015	2014	2015	2014	2015
April	47.0	69.8	83.6	75.3	12.5	11.1
May	80.0	5.8	79.9	69.5	16.9	18.8
June	51.4	42.8	76.2	69.2	21.2	21.3
July	131.6	4.8	73.4	65.3	23.8	24.5
August	19.2	2.6	73.8	63.1	24.2	25.3
September	121.4	63.0	81.8	74.2	18.9	21.8

2.2. Plant materials

Table 3 shows some properties of traditional hybrids in this study. Two high oleic and two high linoleic sunflower hybrids were used. One of the oleic and linoleic hybrids was tolerant to imozamax herbicide in the Clearfield technology.

Table 3. Some properties of traditional sunflower hybrids in this study.

Sunflower hybrids	Seed company	Clearfield/non Clearfield	Oil fatty acid profile
LG 5542 CL	Limagrain	Clearfield	High Linoleic
P64LL05	Pioneer	Non-Clearfield	High Linoleic
Colombi	Syngenta	Clearfield	High Oleic
P64H34	Pioneer	Non-Clearfield	High Oleic

2.3. Application materials

Active ingredients, application rates, application times, trade names, and manufacturer of herbicides are given in *Table 4*. All herbicides were applied backpack sprayer at the recommended dose and time by their manufacturer.

Table 4. Active ingredients, application rates, application times, trade names, and manufacturer of herbicides

Trade name	Manufacturer	Active ingredients, per liter	Dose (ml/ha)	Application time
BonoflanWG	Dow AgroSciences	Benfluralin, 60 g	2500	Pre-Plant
Stomp® Extra	BASF	Pendimethalin, 450 g	3000	Pre-Emergence
Challenge600	Bayer	Aclonifen, 600 g	1250	Post-Emergence
Targa Super	Sumi Agro	Quizalofop-P-Ethyl,50 g	1000	Post-Emergence
Intervix® Pro	BASF	Imazamox, 40 g	1250	Post-Emergence

2.4. Experimental design and treatments

The trials were arranged separately for Clearfield and non-Clearfield cultivars in 2014 and 2015. Each experiment was laid out in a randomized complete block design (RCBD) with a split plot including different herbicide applications and mechanical hoeing for weed control on sunflower cultivars with four replications. “Intervix® Pro” was applied to Clearfield hybrids “LG 5542 CL” and “Colombi”. Other herbicides “BonoflanWG”, “Stomp® Extra”, “Challenge600” and “Targa Super” were applied to non-Clearfield hybrids “P64LL105” and “P64H34”. Each cultivar in replication also had a control plot as mechanical hoeing weed control.

Each plot was set up in planting at 5.0 m × 2.8 m = 14.0 m^2. Planting was done on May 21, 2014, for the first year, and on April 27, 2015, for the second year with an intra-row spacing of 30 cm and a row-to-row spacing of 70 cm. The reason for the late planting in the first year was heavy rainfall. The experimental field each year was fertilized as 300 kg ha-1 with 20-20-0 (NPK) prior to planting. In each plot, plant height, the number of days from planting to 50 % flowering, head diameter, stem diameter, one thousand seeds weight, seed yield, oil content, and oil fatty acids were observed.

2.5. Analysis of pesticide residues

In addition, pesticide (herbicide) residues analysis were done on harvested seeds from each herbicide application plot within each block according to TS EN 15662 by a private firm. In analyses, GC MS/MS and LC MS/MS instruments were used for benfluralin, and pendimethalin, aclonifen and imazamox, respectively. UPLC MS/MS instrument was used to analysis of Quizalofop-P-Ethyl.

2.6. Statistical analysis

Statistical analysis was performed according to standard procedures for a randomized complete block design with split plots separately for Clearfield and non-Clearfield cultivars. The SAS System was used to generate the analysis of variance (ANOVA) for determining treatment effects on the dependent variables (SAS Institute, 1997). Treatment means comparisons were based on F-Protected Least Significance Differences (LSD) comparisons at $P \leq 0.05$.

3. Results and Discussion

In this research, the trials were arranged separately for Clearfield and non-Clearfield cultivars in 2014 and 2015. “Intervix® Pro” was applied to Clearfield cultivars “LG 5542 CL and Colombi”. Other four herbicides “Bonaflan WG, Stomp® Extra, Challenge600, and Targa Super” were applied to non-Clearfield cultivars “P64LL05 and P64H34”. Each cultivar had a control mechanical hoeing weed control on sunflower the plot within each replication. Thus, analysis of variance was done separately for Clearfield and non-Clearfield cultivars.

3.1. Analysis of variance (ANOVA) for sunflower yield and seed oil components

3.1.1. Variance analyses for seed yield and yield components in sunflower hybrids

Table 5. Analysis of variance of some seed yield and yield components in sunflower

Clearfield cultivars	**Plant height**	**Head diameter**	**Stem diameter**	**1000 seed weight**	**Days to 50% flowering**	**Test weight**	**Seed yield**
Y (Year)	3333.97**	4.22**	0.29	0.12	11.28*	0.01	290.65
C (Cultivar)	1275.00**	18.06**	2.31**	25.10	5.28*	24.67**	407.55
A (Application)	1933.33**	0.27	4.33**	45.13	2.53	0.34	293.79
Y*C	223.82**	0.11	0.49*	0.17	2.53	0.03	7378.08*
Y*A	0.24	0.45	0.11	0.25	0.03	9.14	50.45
C*A	12.09*	1.74	4.13**	4.96	1.53	0.14	13.49
Y*C*A	16.06*	1.24	0.07	0.01	0.03	0.02	0.22
CV	1.16	3.81	4.75	5.42	1.27	3.51	10.26
Non Clearfield cultivars	**Plant height**	**Head diameter**	**Stem diameter**	**1000 seed weight**	**Days to 50% flowering**	**Test weight**	**Seed yield**
Y (Year)	2472.87**	48.88**	1.62*	0.16	56.11**	0.61	63429.28**
C (Cultivar)	416.42**	177.40**	0.74*	164.37*	66.61**	1.46	2921.07
A (Application)	468.97**	0.77	1.18**	51.67	8.89**	4.22	1340.64
Y*C	0.08	2,96	0.46	0.77	3.61*	0.20	3015.35
Y*A	246.23**	0.35	0.09	0.31	0.46	0.56	563.62
C*A	398.21**	3.66	1.92**	193.2**	9.27**	3.18	523.25
Y*C*A	269.81**	1.14	0.33	0.82	1.33*	0.55	1052.91
CV	2.11	9.83	7.17	7.22	1.00	3.81	14.37

* and ** : Significant differences are shown at $P < 0.05$ and $P < 0.01$, respectively

Variance analyses of sunflower seed yield and yield components are given separately for Clearfield and non-Clearfield cultivars in *Table 5*. Plant height was significantly affected by year, cultivar, application, and interactions of year x application, cultivar x application, and year x cultivar x application in Clearfield and non-Clearfield cultivars. Only, year and cultivar had a significant effect on head diameter in both groups. Stem diameter was affected significantly by cultivar, application, year x application, and cultivar x application in Clearfield hybrids while the significant effective factors were the year, cultivar, application, and cultivar x application in non-Clearfield hybrids. There was no significant effective factor on 1000 seed weight in Clearfield cultivar, although cultivar and cultivar x application factors had a significant effect on this character in non-Clearfield cultivars. In Clearfield hybrids, year and cultivar had a significant effect on days from planting to 50% flowering time. On the other hand, the character was significantly affected by year, cultivar, application, and interactions of year x cultivation, cultivar x application, and year x cultivar x application in non-Clearfield hybrids. For test weight, only the cultivar effect was significant in Clearfield hybrids. It was not found effective factor on test weight for non-Clearfield hybrids. Year x cultivar and year had significant effects on seed yield in Clearfield and non-Clearfield hybrids, respectively.

3.1.2. Variance analyses for seed oil content and fatty acids in sunflower

Variance analyses of sunflower oil content and fatty acids are given separately for Clearfield and non-Clearfield cultivars in *Table 6*.

Table 6. Analysis of variance of seed oil content and percentage of fatty acids in sunflower

Clearfield cultivars	Seed oil content	C16:0 Palmitic acid	C18:0 Stearic acid	C18:1 Oleic acid	C18:2 Linoleic acid
Y(Year)	5.07	0.17	1.42**	28.28	23.21
C (Cultivar)	30.69**	14.20**	1.22**	13763.9**	12667.2**
A(Application)	0.99	0.03	0.06*	1.04	1.66
Y*C	2.14	0.27*	0.33**	0.63	0.47
Y*A	1.62	0.12	0.01	13.55	7.73
C*A	0.12	0.14	0.03	0.13	0.34
Y*C*A	0.01	0.05	0.03	37.37*	41.29*
CV	3.39	4.61	3.45	4.69	10.18
Non-Clearfield cultivars	**Seed oil content**	**C16:0 Palmitic acid**	**C18:0 Stearic acid**	**C18:1 Oleic acid**	**C18:2 Linoleic acid**
Y(Year)	257.22**	0.01	0.01	449.07**	654.25**
C (Cultivar)	289.98**	77.36**	13.3**	42187.6**	38949.1*
A(Application)	5.71	0.13	0.10	16.12	0.84
Y*C	61.65**	0.57	0.37*	19.52	5.09
Y*A	5.87	0.15	0.05	14.24	1.55
C*A	15.30*	0.35	0.07	20.74	5.96
Y*C*A	13.93**	0.38	0.04	19.01	7.08
CV	5.22	9.33	8.61	8.54	12.77

* and **: Significant differences are shown at $P < 0.05$ and $P < 0.01$, respectively

Differences between cultivars for seed oil content were significant in both groups. In addition to this factor, year, year x cultivar, cultivar x application, and year x cultivar x application had significant effects on seed oil content in non-Clearfield cultivars. Cultivar had also a significant effect on the percentage of palmitic acid in both groups. In Clearfield cultivars, a significant effect was also found for year x cultivar interactions. Year, cultivar, application, and year x cultivar interaction had a significant effect on the percentage of stearic acid in Clearfield cultivars, although the character was affected significantly by cultivar and year x cultivar interactions in non-Clearfield cultivars. Percentage of oleic and linoleic acids were affected by cultivar and year x cultivar x application interaction in Clearfield cultivars, while cultivar and year had a significant effect on these fatty acids in non-Clearfield cultivars.

3.2. Mean comparisons of yield and oil components for factors

3.2.1. Means of applications according to years for seed yield and yield components

According to year variation for Intervix®Pro herbicide application (*Table 7*), plant height and head size in 2015 were smaller than in 2014. In addition, in the second year, the number of days from planting to 50% flowering was decreased. Although planting in 2015 was about one month early than in 2014, this is thought to be caused by the low rainfall until the flowering in the second year. In other herbicide group cultivars, stem diameter was also decreased in addition to these characters. On the opposite of this, the seed yield of non-Clearfield cultivars significantly increased in 2015. It is thought that this could be due to the fact that the second group varieties enter the generative period earlier than the first group and make better use of the advantage of benefiting from soil moisture with early planting and escape from higher temperatures during grain filling (Soriano et al., 2004; Pepo and Novak, 2016; Debake, et al., 2017).

Table 7. Means of applications according to years for seed yield and yield components

Herbicide	Year	Plant height (cm)	Head diameter (cm)	Stem diameter (cm)	1000 seed weight (g)	Days to 50% flowering (days)	Test weight (kg/hl	Seed yield (kg ha^{-1})
Intervix® Pro	2014	149.24a*	18.88a	5.93	68.86	76.13a	34.91	2287.30
	2015	128.82b	18.15b	5.74	68.73	74.94b	34.88	2366.10
	LSD	1.19	0.52	0.20	2.74	0.71	0.90	175.7
Other herbicides**	2014	128.13a	16.30a	5.84a	73.91	72.25a	34.79	1782.0b
	2015	117.00b	14.74b	5.56b	73.82	70,58b	34.61	2359.3a
	LSD	1.16	0.68	0.18	2.39	0.32	0.59	132.7

*: Within each column in each group, means followed by the same letters are not significantly different at P ≤ 0.05.
**: Bonoflan WG, Stomp® Extra, Challenge600, Targa Super

3.2.2. Means of applications according to years for seed oil content and fatty acids

In seed oil content and fatty acids of Clearfield cultivars (*Table 8*), there were no statistically significant differences between 2014 and 2015. Unlike that, seed oil content and percentage of linoleic acid in second-year non-Clearfield cultivars were lower than in the first year. Onemli (2012a) and Onemli (2012b) suggested that high temperatures and drought stress caused decreases in seed oil content and the percentage of linoleic acid in sunflower seed oil. Although they were not statistically significant in Clearfield cultivars, seed oil contents and percentage of linoleic acid in seed oil in 2014 depend on higher rainfall and lower temperatures were higher than in 2015.

Table 8. Means of applications according to years for seed oil content and fatty acids

Herbicide	Year	Seed oil content (%)	C16:0 Palmitic acid (%)	C18:0 Stearic acid (%)	C18:1 Oleic acid (%)	C18:2 Linoleic acid (%)
Intervix® Pro	2014	42.67	4.96	2.94a	60.70	29.70
	2015	41.87	5.10	2.51b	62.46	28.00
	LSD	1.05	0.17	0.07	2.13	2.16
Other herbicides**	2014	44.04a*	4.63	3.01	59.95b	30.82a
	2015	40.46b	4.64	3.00	64.69a	25.11b
	LSD	0.99	0.19	0.12	2.38	1.60

: Within each column in each group, means followed by the same letters are not significantly different at P ≤ 0.05.: BonoflanWG, Stomp® Extra, Challenge600, Targa Super

3.2.3. Means of applications according to cultivars for seed yield and yield components

Table 9 shows cultivar variations for seed yield and yield components. High oleic Clearfield genotype "Colombi" had statistically higher plant height, head diameter, days from planting to 50% flowering and test weight, and lower stem diameter than "LG5542CL" cultivar. The high oleic non-Clearfield cultivar "P64H34" had higher plant height, stem diameter, 1000 seed weight, days from planting to 50% flowering, test weight and seed yield, and lower head diameter than "P64LL05" cultivar. Pepo and Novak (2016) put similar correlations between photosynthetic traits and yield depending on genotype in sunflower.

Table 9. Means of applications according to cultivars for seed yield and yield components

Herbicide	Cultivar	Plant height (cm)	Head diameter (cm)	Stem diameter (cm)	1000 seed weight (g)	Days to 50% flowering (days)	Test weight (kg/hl	Seed yield (kg ha^{-1})
Intervix® Pro	LG5542CL	132.72b	17.76b	6.11a	69.68	75.13b	34.01b	2295.2
	Colombi	145.34a*	19.26a	5.57b	67.91	75.94a	35.77a	2358.2
	LSD	1.19	0.52	0.20	2.74	0.71	0.90	175.7
Other herbicides**	P64LL05	120.29b	17.01a	5.60b	72.43b	70.50b	34.56b	1976.4b
	P64H34	124.85a	14.03b	5.80a	75.29a	72.33a	34.83a	2164.9a
	LSD	1.16	0.68	0.18	2.19	0.32	0.59	132.7

*: Within each column in each group, means followed by the same letters are not significantly different at P ≤ 0.05.
**: BonoflanWG, Stomp® Extra, Challenge600, Targa Super

3.2.4. Means of applications according to cultivars for seed oil content and fatty acids

Table 10 shows high linoleic genotypes (LG5542CL and P64LL05) in both groups with higher oil content in seeds than high oleic genotypes (Colombi and P64H34). The oleic types have been developed recently and the genetic resource in this type for oil and yield improvement is very poor compared to the linoleic types (Zhou, et al., 2018). There were known differences between the oleic and linoleic types in terms of fatty acids. But, both linoleic types had a higher percentage of oleic acids and a lower percentage of linoleic acids than their normal properties depending on higher temperatures (Onemli, 2012a; Onemli, 2012b)

Table 10. Means of applications according to cultivars for seed oil content and fatty acids

Herbicide group	Cultivar	Seed oil content (%)	C16:0 Palmitic acid (%)	C18:0 Stearic acid (%)	C18:1 Oleic acid (%)	C18:2 Linoleic acid (%)
Intervix® Pro	LG5542CL	43.25a	5.70a	2.92a	40.85b	48.75a
	Colombi	41.29b	4.36b	2.53b	82.32a	8.96b
	LSD	1.05	0.17	0.07	2.13	2.16
Other herbicides**	P64LL05	44.16a	5.62a	3.41a	39.36b	50.03
	P64H34	40.35b	3.65b	2.59b	85.28a	5.90
	LSD	0.99	0.19	0.12	2.38	1.60

*: Within each column in each group, means followed by the same letters are not significantly different at P ≤ 0.05.

3.2.5. Means of applications according to subjects for seed yield and yield components

Variations in seed yield and yield components by herbicide application are given in *Table 11*. Intervix®Pro herbicide had a negative effect on plant height and stem diameter in Clearfield cultivars. The effects of this herbicide on seed yield or other yield characters were not found significant.

In non-Clearfield cultivars, the shortest plant height was observed in the control application (hoeing weed control) while Stomp®Extra and Targa Super applications were in the highest plant height group. Bonaflan WG and Challenge600 had also higher plant heights than hoeing weed control. There was no significant group for head diameter in non-Clearfield cultivars. Stomp®Extra had the highest stem diameter. Challenge600 and Targa Super had also higher stem diameters than hoeing weed control. For 1000 seed weight, all herbicide applications were in the same group as hoeing weed control applications although two significant groups were observed. Days from planting to 50% percent were decreased by Stomp®Extra application. Other herbicide applications were in the same group with hoeing weed control for this character. All herbicide applications for test weight and seed yield were also in the same group as hoeing weed control applications although there were two significant groups. Seed yield in Bonaflan WG was significantly higher than Targa Super.

Table 11. Means of applications according to subjects for seed yield and yield components

Clearfield cultivars	**Plant height (cm)**	**Head diameter (cm)**	**Stem diameter (cm)**	**1000 seed weight (g)**	**Days to 50% flowering (days)**	**Test weight (kg/hl)**	**Seed yield (kg ha^{-1})**
Hoeing	146.80a*	18.61	6.20a	67.61	75.25	34.99	2437.98
Intervix® Pro	131.26b	18.42	5.47b	69.98	75.81	34.79	2377.38
$LSD_{0.05}$	1.19	0.52	0.20	2.74	0.71	0.90	181.68
Non-Clearfield cultivars	**Plant height (cm)**	**Head diameter (cm)**	**Stem diameter (cm)**	**1000 seed weight (g)**	**Days to 50% flowering (days)**	**Test weight (kg/hl)**	**Seed yield (kg ha^{-1})**
Hoeing	113.96c	15.82	5.38c	73.79ab	72.06a	34.75ab	2036.5ab
Bonaflan WG	122.34b	15.49	5.54bc	76.25a	71.63a	34.89a	2251.3a
Stomp® Extra	126.43a	15.40	6.10a	71.78b	70.13b	35.25a	2147.6ab
Challenge600	122.25b	15.25	5.79b	74.94ab	71.69a	33.86b	2100.7ab
Targa Super	127.86a	15.64	5.69b	72.55ab	71.56a	34.74ab	2028.2b
$LSD_{0.05}$	1.83	1.08	0.29	3.77	0.51	0.94	214.95

*: Within each column in each group, means followed by the same letters are not significantly different at P ≤ 0.05.

3.2.6. Means of applications according to subjects for seed oil content and fatty acids

Variations in seed oil content and fatty acids by herbicide application are given in *Table 12*. It was determined significant group for the only percentage of stearic acid in Clearfield cultivars. The percentage of stearic acid rate in seed oil was decreased significantly by Intervix®Pro application according to hoeing weed control. In non-Clearfield cultivars, herbicide applications did not create significant groups in seed oil content and fatty acids.

Table 12. Variations in seed oil content and fatty acids by herbicide application

Clearfield cultivars	**Seed oil content (%)**	**C16:0 Palmitic acid (%)**	**C18:0 Stearic acid (%)**	**C18:1 Oleic acid (%)**	**C18:2 Linoleic acid (%)**
Hoeing	42.09	5.06	2.77a*	61.76	28.62
Intervix® Pro	42.44	5.00	2.68b	61.40	29.08
$LSD_{0.05}$	1.05	0.17	0.07	2.13	2.16
Non-Clearfield cultivars	**Seed oil content (%)**	**C16:0 Palmitic acid (%)**	**C18:0 Stearic acid (%)**	**C18:1 Oleic acid (%)**	**C18:2 Linoleic acid (%)**
Hoeing	42.31	4.58	2.90	63.21	27.61
Bonaflan WG	42.63	4.78	3.09	60.59	28.08
Stomp® Extra	42.32	4.61	3.06	62.47	28.12
Challenge600	41.24	4.65	3.00	62.72	27.87
Targa Super	42.76	4.55	2.95	62.61	28.16
$LSD_{0.05}$	1.56	0.31	0.18	3.77	2.53

*: Within each column in each group, means followed by the same letters are not significantly different at P ≤ 0.05.

3.2.7. Means of applications according to year and cultivar interaction for some seed yield and oil characters

Variations in seed yield and oil characters by herbicide applications depending on year and cultivar are given in *Table 13*. Intervix®Pro application had no significant effect on seed yield in both cultivars and both years. This herbicide increased the number of days from planting to 50% flowering according to hoeing weed control in LG 5542CL in 2015. Intervix®Pro decreased plant height in LG 5542CL and Colombi hybrids in both years. Seed oil content, percentage of oleic acid, and linoleic acid were not affected as statistically significant by Intervix®Pro application similar seed yield.

Table 13. Means of applications according to year and cultivar interaction for seed yield and oil characters

Cultivar	Year	Application	Seed yield (kg ha^{-1})	Days to 50% flowering	Plant height (cm)	Seed oil content (%)	C18:1 Oleic acid	C18:2 Linoleic acid
LG 5542CL	2014	Hoeing	2445.2	75.50	149.46a	44.03	41.67	47.73
		Intervix® Pro	2542.2	76.50	131.10b	43.78	37.98	51.23
		$LSD_{0.05}$	451.3	3.18	7.00	2.37	9.49	8.83
	2015	Hoeing	2275.4	73.75b	132.75a	42.23	40.25	49.52
		Intervix® Pro	2225.2	74.75a	117.56b	42.95	43.48	46.51
		$LSD_{0.05}$	274.1	0.99	2.24	4.23	4.62	4.44
Colombi	2014	Hoeing	2224.2	76.25	164.73a	41.40	81.40	10.24
		Intervix® Pro	2298.6	76.25	151.66b	41.46	81.77	9.62
		$LSD_{0.05}$	405.4	1.30	1.30	3.51	8.26	8.99
	2015	Hoeing	2614.9	75.50	140.27a	40.71	83.73	7.05
		Intervix® Pro	2635.8	75.75	124.71b	41.59	82.38	8.96
		$LSD_{0.05}$	290.2	0.80	2.35	3.16	2.33	2.80
P64LL05	2014	Hoeing	1810.1	71.75	117.13d	44.55b	38.16	51.73
		Bonaflan WG	1783.1	71.50	122.00c	44.45b	36.46	52.91
		Stomp® Extra	1691.2	71.00	123.82c	45.08ab	34.58	54.94
		Challenge600	1683.6	71.50	128.46b	45.21ab	38.40	51.30
		Targa Super	1579.4	72.00	137.68a	46.07a	34.87	54.84
		$LSD_{0.05}$	299.2	1.55	2.19	1.12	4.78	4.34
	2015	Hoeing	2303.8	69.75b	115.10b	42.70	42.57	46.68
		Bonaflan WG	2461.0	68.75c	111.76c	42.87	42.10	47.43
		Stomp® Extra	2461.0	68.75c	111.76c	43.50	42.01	46.69
		Challenge600	2338.0	68.75c	110.89c	44.34	41.84	47.07
		Targa Super	2413.2	71.25a	124.28a	42.79	42.58	46.72
		$LSD_{0.05}$	451.4	0.69	2.36	3.43	3.30	3.66
P64H34	2014	Hoeing	1746.0	74.25a	121.80c	43.01ab	83.23	8.61
		Bonaflan WG	1962.6	73.75a	135.22b	43.61a	83.15	8.98
		Stomp® Extra	2108.9	71.00c	135.32b	42.88ab	84.80	7.27
		Challenge600	2061.2	73.50ab	139.28a	43.00ab	82.10	9.59
		Targa Super	1886.9	72.25bc	120.57d	42.59b	83.76	8.09
		$LSD_{0.05}$	467.4	1.25	1.16	0.97	9.73	9.26
	2015	Hoeing	2286.1b	72.50a	101.80d	38.98a	88.87	3.41
		Bonaflan WG	2798.4a	72.50a	120.39b	39.58a	80.67	3.00
		Stomp® Extra	2329.4b	69.75c	134.83a	37.82ab	88.48	3.57
		Challenge600	2320.1b	73.00a	110.37c	32.42b	88.53	3.51
		Targa Super	2233.3b	70.75b	128.91a	39.59a	89.24	2.97
		$LSD_{0.05}$	447.6	0.51	7.17	5.78	12.29	1.63

*: Within each column in each group, means followed by the same letters are not significantly different at $P \leq 0.05$.

In non-Clearfield cultivars, Bonaflan WG increased seed yield according to hoeing weed control in P64H34 in 2015. In this group, there was no significant group in seed yield for applications for P64H34 in 2014, and for P64LL05 in both years. Targa Super had the highest number of days from planting to 50% flowering in the second year of P64LL05 hybrid although other herbicide applications (Bonaflan WG, Stomp®Extra and Challenge600) in this group caused early flowering than hoeing weed control. Stomp®Extra and Targa Super applications on P64H34 hybrid decreased the number of days from planting to 50% flowering according to hoeing weed control in both years. Targa Super application on P64LL05 gave the highest plant height in both years. Hoeing weed control had the shortest plant height for this hybrid in the first year while it was in the second-highest plant height group in 2015. For plant height of P64H34, Challenge600 had the highest value in 2014, while Stomp®Extra and Targa Super were in the highest plant height group. In the first year, Bonaflan WG. Stomp®Extra had higher plant heights than hoeing weed control in P64H34. In the second year, the plant height of hoeing weed control for P64H34 was the shortest within all applications. Targa Super application on P64LL05 in 2014 gave higher seed oil content than hoeing weed control although the other applications were in the same group as the control application. There was no significant difference between herbicide applications except Challenge600 and hoeing weed control for seed oil content of P64H34. There was no significant group for the percentage of oleic and linoleic acids in non-Clearfield hybrids.

3.3. Pesticide residues in harvested seeds of herbicide application plots.

Pesticide residues in harvested seeds of herbicide application plots are given in *Table 14*. The detected residue of herbicide active ingredients in the seed of herbicide application plots was not exceeded international acceptable limits.

Table 14. Pesticide residues in harvested seeds of herbicide application plots.

Trade name	Limit (LOQ)	Unit	Result	Instrument Analysis method
BonoflanWG	0.01	mg/kg	Not Detected	GC MS/MS TS EN 15662
Stomp® Extra	0.01	mg/kg	Not Detected	LC MS/MS TS EN 15662
Challenge600	0.01	mg/kg	Not Detected	LC MS/MS TS EN 15662
Targa Super	0.01	mg/kg	Not Detected	UPLC MS/MS J. of AOAC Int. vol. 90. No.2.2017
Intervix® Pro	0.01	mg/kg	Not Detected	LC MS/MS TS EN 15662

4. Discussion

According to results, the application of Intervix®Pro including 40 g/l Imazamox active ingredients caused decreases in plant height and stem diameter and increases the percentage of stearic acid in seed oil according to hoeing weed control in sunflower.

In comparison with hoeing weed control, the application of Bonaflan WG including 60 g/l Benfluralin active ingredients increased the seed yield of one non-Clearfield cultivar in 2015.

Stomp®Extra including 450 g/l Pendimethalin active ingredients generally increased plant height and stem diameter and decreased the number of days from planting to 50% flowering according to hoeing weed control.

Challenge600 including 600 g/l Aclonifen active ingredients generally caused increasing plant height and stem diameter according to hoeing weed control. In addition, this herbicide delayed flowering in P64LL05 cultivar in dry 2015.

Targa Super including 50 g/l Quizalofop-P-Ethyl active ingredients had also increases in plant height and stem diameter compared with hoeing weed control. This herbicide delayed flowering in P64LL05 although it decreased the number of days from planting to 50% flowering in P64H34 hybrid especially dry growing season in 2015. Targa Super had higher seed oil content than hoeing weed control in P64LL05 in 2014.

Simic et al. (2011) found negative effects of imidazoline herbicides on seed yield and oil content in sunflower when the application is late. They found a positive effect of IMI herbicides on plant characters, unlike our research. Because there was no weed control in their control plots. Reddy et al. (2012) found negative effects of herbicides with pendimethalin active ingredients on seed yield components. There are many research results on the phytotoxic effects of herbicides on crops (Delchev, 2013; El-Rokiek et al., 2013)

Tichý et al. (2018) determined the negative effects of herbicides on seed yield components, especially under drought soil and climatic conditions. Renukaswamy et al. (2012) and Suryavanshi et al. (2015) found the highest yields in the herbicide-free plot. They indicated that herbicide applications had a negative effect on seed yield components. Results of previous research with IMI group herbicides are similar to our study results. But finding results with other herbicides applicated non-Clearfield cultivars in this study are quite different than previous studies.

The absence of herbicide residues in the seeds is a pleasing result. In this result, application time and dose are important. Increased herbicide doses can create pesticide residue in seeds (Serim and Maden, 2014).

The results showed that Intervix®Pro application on Clearfield cultivars causes stress on plant characters resulting in losses in seed yield, especially in drought conditions although it was not found statistically significant differences for seed yield in this research. Whereas positive effects of other herbicides applicated non-Clearfield hybrids on plant characters provide increases in seed yield except Targa Super application. This positive effect of herbicides on the seed yield even when their effects on weed control are not taken into account, could be statistically significant as BonoflanWG in drought conditions in this research unlike the results of previous studies. Although root measurements were not taken in this research, this is thought to be due to the fact that some herbicides encourage root development, and provide water and nutrient taking for a longer period of time in the generative period such as in cotton (Marple et al., 2007).

5. Conclusion

According to our results, there is no statistically significant difference in seed yield of cultivars between any Intervix® Pro herbicide application and mechanical hoeing weed control. On the other hand, this herbicide may be a negative effect on yield components such as plant height and stem diameter, especially in stress conditions such as drought. Unlike these herbicide results, pre-plant herbicide “Bonoflan” can have significantly positive effects on seed yield and yield components compared with mechanical weed control in low precipitation conditions. These results showed that producers need to be careful to avoid creating stress on plants. when applying IMI and other postemergence herbicides, especially in drought conditions. In these conditions, weed control by mechanical hoeing should come to the fore than herbicide application. The results showed that herbicides especially post-emergence applications under stress conditions can adversely affect agronomic yield and seed oil components in sunflower. Considering the damage caused by pesticides to the environment, herbicide application should be avoided when mechanical hoeing is economical or cost-effective.

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