DOI: 10.29050/harranziraat.1465501
Harran Tarım ve Gıda Bilimleri Derg. 2024, 28(2): 222-234

Research Article/Araştırma Makalesi

Does weed infestation alter the population density of harmful leafhopper species in second crop maize?

Yabancı otlar ikinci ürün mısırdaki zararlı yaprakpiresi türlerinin popülasyon yoğunluğunu değiştirir mi?

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To cite this article:
Kaplan Yavuz, E., Tunaz, H. & Mutlu, Ç. (2024). Does weed infestation alter the population density of harmful leafhopper species in second crop maize?. Harran Tarım ve Gıda Bilimleri Dergisi, 28(2): 222-234

DOI: 10.29050/harranziraat.1465501

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Received Date:
05.04.2024
Accepted Date:
10.06.2024

ABSTRACT

Weed-insect interaction has been studied for decades to determine the role of weeds in insect infestation. This study investigated the impact of weed density on the population density of important leafhopper species (Cicadellidae: Hemiptera) and their egg parasitoid *Anagrus atomus* (L.) (Hymenoptera: Chalcidoidea) in maize (*Zea mays* L.) planted as second crop in Şanlıurfa province, Türkiye during 2022 and 2023. Population densities of harmful leafhopper species, i.e., *Zyginidia sohrab* (Zachvatkin), *Empoasca decipiens* (Paoli), *Asymmetrasca decedens* (Paoli), *Psammotettix striatus* (Linnaeus), and their parasitoid, i.e. *A. atomus* were monitored by yellow sticky traps (RAL-1016) under weedy and weed-free conditions. Three traps were hung in each experimental unit and the densities of target species were recorded weekly. The population densities of leafhopper species feeding on *Sorghum halepense* (L.) (Johnsongrass) and the effect of *A. atomus* on their population density were also determined in weedy treatment. A total 15 maize leaves were taken from both weedy and weed-free treatments, and *S. halepense* leaf tissues containing leafhopper eggs parasitized by *A. atomus* were counted weekly.
Weed density had non-significant effect on the population density of *Z. sohrab* during both years. Contrastingly, increasing weed density increased the population density of *E. decipiens* & *A. decedens* complex in 2022. Nevertheless, weed density had non-significant effect on the population density of *E. decipiens* & *A. decedens* complex during 2023. Weedy treatment recorded higher population density of *P. striatus* (140 and 100 adults, respectively); however, both weedy and weed-free treatments recorded similar density (125 and 97 adults) during 2023. Weed density proved a significant factor in increasing *A. atomus* density. A total of 2935 parasitized eggs were recorded from the weedy treatment, whereas 1609 parasitized eggs were recorded from weed-free treatment. Although direct relationship between leafhoppers and weed density remains uncertain, integrated pest management strategies must consider phytophagous insects feeding on weeds at field edges and within fields and the natural enemy complex.

Key Words: Sticky trap, density, pest, parasitoid, johnsongrass

ÖZ

Yabancı otlar ile zararlı böcekler arasındaki etkileşim yıllardır yabancı otların böcek istilasındaki rolünü belirlemek için incelenmektedir. Bu çalışma ikinci ürün mısırda (*Zea mays* L.) yabancı ot yoğunluğunun önemli yaprakpireleri (Cicadellidae: Hemiptera) ile bunların yumurta parazitoiti *Anagrus atomus* (L.) (Hymenoptera: Chalcidoidea)'un popülasyon yoğunluğuna etkisinin belirlenmesi amacıyla Şanlıurfa ilinde 2022 ve 2023 yıllarında yürütülmüştür. Çalışmada zararlı yaprakpireleri, *Zyginidia sohrab* (Zachvatkin), *Empoasca decipiens* (Paoli), *Asymmetrasca decedens* (Paoli), *Psammotettix striatus* (Linnaeus.), ile *A. atomus*'un popülasyonu yapışkan tuzaklar (RAL-1016) ile yabancı otlu ve yabancı ot içermeyen koşullarda izlenmiştir. Her deneme alanına 3'er adet sarı yapışkan tuzağı asılarak

hedef türlerin yoğunlukları haftalık olarak kaydedilmiştir. Yabancı otlu deneme alanında *Sorghum halepense* (L.) (Kanyaş) üzerinde beslenen yaprakpiresi türleri ve *A. atomus*'un popülasyon yoğunluğuna olan etkiside ayrıca belirlenmiştir. Toplamda her iki deneme alanından haftalık olarak 15 adet mısır yaprağı ve *S. halepense* yaprağı alınarak yaprak dokusu içinde *A. atomus* tarafından parazitlenmiş yaprakpiresi yumurtaları sayılmıştır.
Yabancı ot yoğunluğunun her iki yılda *Z. sohrab*'ın popülasyon yoğunluğu üzerinde anlamlı bir etkisinin olmadığı, buna karşın *E. decipiens* & *A. decedens* kompleksi popülasyonunu artırdığı görülmüştür. Ancak, 2023 yılında yabancı ot yoğunluğunun *E. decipiens* & *A. decedens* kompleksi popülasyon yoğunluğu üzerinde anlamlı bir etkisi bulunmadığı kaydedilmiştir. *Psammotetix striatus* popülasyonu 2022 yılında yabancı otlu deneme alanlarında daha fazla bulunmuş (sırasıyla 140 ve 100 ergin), buna karşın 2023 yılında ise önemli bir fark görülmemiştir (125 ve 97 ergin). Yabancı yoğunluğunun *A. atomus*'un yoğunluğunu önemli ölçüde artıran bir faktör olduğu kaydedilmiştir. Yabancı otlu deneme uygulamasından toplamda 2935 adet parazitlenmiş yumurta kaydedilmiş, buna karşın yabancı otsuz alanda toplamda 1609 adet parazitlenmiş yumurta kaydedilmiştir. Yabancı ot yoğunluğu ile yaprakpireleri arasındaki doğrudan ilişki belirsiz olsa da, tarla kenarında ve içinde bulunan yabancı otlar üzerinde beslenen fitofag böcekler ile doğal düşman kompleksine göre entegre zararlı yönetim stratejilerinin uygulanmasının doğru olacağı düşünülmektedir

Anahtar Kelimeler: Yapışkan tuzak, yoğunluk, zararlı böcek, parazitoit, kanyaş

Introduction

Pests are a significant hurdle to the productivity and quality of agricultural crops. (Manosathiyadevan et al., 201). The Cicadellidae (Hemiptera) family consisting of leafhoppers is prominent among these pests infesting various crops (Maramorosch and Harris, 1979). The Cicadellidae species are either monophagous or polyphagous and cause significant economic crop losses by damaging different phenological stages of maize plants (Mutlu et al., 2008a). The damage primarily results from the insect feeding on plant sap and the clogging of the vascular tissues by toxic substances secreted by insects into the plant, which obstruct the transport of nutrients within the plant. Additionally, some species act as vectors for plant virus diseases, resulting in significant economic losses (Nielson, 1985; Nault and Ammar, 1989; Backus et al., 2005; Paradel et al., 2014). Leafhoppers are regarded as an important pest group in agricultural production and require effective management measures (Mutlu and Sertkaya, 2015a; Ersin et al., 2017).

Several studies have investigated the bioecology, biology, and economic damage thresholds of species belonging to the Cicadellidae family in Türkiye (Mutlu et al., 2008b; Yılmaz and Karsavuran, 2010; Mutlu and Sertkaya, 2015b; Kılıç and Sertkaya, 2019; Akmeşe and Sertkaya, 2021, Baran Yazıcı et al., 2023). More than 27 species of leafhoppers have been identified in the Southeastern Anatolia region of the country, where maize is intensively cultivated as main and second crop (Mutlu et al., 2008b). The most abundantly observed species are *Zyginidia sohrab* (Zachvatkin), *Empoasca decipiens* (Paoli), *Asymmetrasca decedens* (Paoli), and *Psammotettix striatus* (Linnaeus) (Mutlu et al., 2008a; Atmaca et al., 2021). *Zyginidia sohrab* is prevalent during the initial phenological stage (2-4 leaf) of second crop maize, leading to significant damages to seedlings (Mutlu et al., 2008a; Mutlu and Sertkaya, 2015a). It has been emphasized that some narrow-leaved weed species (i.e., Johnsongrass, cockspur grass, bermuda grass, and nutgrass) found along the edges and inside field of main and second crop maize significantly increase in leafhopper populations (Mutlu et al., 2008a; Mutlu and Sertkaya, 2015a; Baran Yazıcı et al., 2023).

Weed-insect interaction has been a rich topic of interest for decades. Weeds infesting cultivated fields serve as hosts for harmful insects, and simultaneously play a crucial role in supporting the populations of beneficial insect species (Norris and Kogan, 2000). Andow (1983) reported that higher plant diversity in agricultural ecosystems increases the densities of phytophagous insect species and their natural enemies (parasitoids and predators). Weeds continuously persist in agroecosystems and could not be eradicated; therefore, harmful insect species continuously persist on the weeds. Hence, harmful insect populations prevailing on the weeds should be considered while designing pest management programs (Schellhorn and Sork, 1997). A complex relationship exists between leafhoppers and weeds (Van Emden, 1981). Weeds can increase the population density of harmful leafhoppers (Oloumi-Sadeghi et al., 1987; Paradel et al., 2014), nevertheless this relationship is not precisely symbiotic (Van Emden, 1981). Leafhoppers can damage several plants, including weeds and higher densities of leafhoppers are recorded in the areas with higher weed infestation (Mutlu and Sertkaya, 2015b). Weeds provide feeding habitat to leafhoppers, leading to a significant increase in their density (Oloumi-Sadeghi et al., 1987; Marques et al., 2012)

The interaction between leafhoppers and weed density has not been directly studied. However, some studies have investigated the interactions between weeds, arthropod pests, and their natural enemies (Altieri and Whitcomb, 1979; Sadeghi et al., 1989; Norris ve Kogan, 2000; Barbercheck and Wallace, 2021). It is suggested that weeds can serve as alternative hosts for beneficial insects, which indirectly affects the density and distribution of arthropod pests, including leafhoppers (Altieri and Whitcomb, 1979; Sadeghi et al., 1989; Norris and Kogan, 2000).

Although the direct relationship between leafhoppers, weed species and their densities remains uncertain, weeds and other environmental factors can affect the abundance and distribution of leafhoppers and their egg parasitoids in agricultural ecosystems. Hence, the major objective of the current study was to investigate the impact of narrow-leaved weeds (present along the edges and within second crop maize fields) on the population density of important leafhopper species and their egg parasitoid, *A atomus* , in maize plants.

Materials and Methods

Materials

The materials used in the study consisted of second crop maize plants, leafhopper species (*Z. sohrab*, *A. decedes* & *E. decipiens*, *P. striatus*), egg parasitoid *A. atomus*, plexi glas yellow sticky traps with RAL code 1016 (20×25 cm dimension), insect adhesive glue (Tangle-Trap), magnifying glass with light and stand, 1.5 m iron rods, microscope, and other laboratory equipment.

Methods

The effect of weeds on leafhopper populations and their parasitoid Anagrus atomus in second crop maize

This study was conducted at Büyükördek village situated in the central district of Şanlıurfa province. The village is well known for widespread cultivation of both main and second-crop maize. The experimental field (coordinates: 37.373164 °N, 38.662934 °E) covered a 50-decare planted with second crop maize during 2022 and 2023. The experiments were set up according to randomized complete block design with two treatments, i.e., weedy, and weed-free. The experimental blocks (50m × 10m) were divided into two parts, i.e., weedy, and weed-free. At least 50-meter distance was maintained between the blocks. Herbicide Ghibli (Syngenta) (220 g/L Dicamba & 50 g/L Nicosulfuron active ingredients) was applied at the rate of 1200 ml per hectare in weed-free treatment with a field sprayer during the 2-4 true leaf stage of maize plants. Furthermore, weeds emerging after irrigation were manually eliminated from the weed-free treatment. It was observed that the inter-row spaces of maize plants were mostly occupied by Johnson grass (*Sorghum halepense* (L), purslane (*Portulaca oleracea* L.), and nutgrass (*Cyperus rotundus* L.) in weed-free treatment.

Three yellow sticky traps coated with insect adhesive glue (Tangle-Trap) were hung on iron rods at a height of ~1 meter above the ground in both treatments (Mutlu and Sertkaya, 2015a). The sticky traps were replaced weekly with new ones, and the leafhoppers (*Z. sohrab*, *A. decedens* & *E. decipiens* and *P. striatus*) stuck to both sides of the traps were counted using magnifying glass with light and stand.

Additionally, the number of adult *A. atomus* individuals adhered to the yellow sticky traps was carefully counted to determine the weekly population density of the parasitoid. Moreover, 15 leaves were collected from maize plants in each treatment, and the leafhopper eggs parasitized by *A. atomus* within the leaf tissue were counted (Mutlu and Sertkaya, 2015b). Simultaneously, 15 leaf samples from *S. halepense* were randomly collected from weedy treatment, and the presence of parasitized eggs within the leaf tissue was determined. The weekly collected data were analyzed by one-way analysis of variance (ANOVA) technique (Steel et al., 1997) to infer the differences between weedy and weed-free treatments for leafhopper and parasitoid density. The means were compared by the least significant difference (LSD) post-hoc test. The analyses were conducted on SPSS statistical software version 20.0 (IBM SPSS Inc., 2012). The graphical representation of the data was performed using Microsoft Excel program in Office 365 version.

Results and Discussion

The effect of weed infestation on leafhopper populations and their parasitoid Anagrus atomus in second crop maize

The population densities of important leafhopper species recorded from weedy and weed-free treatments during 2022 and 2023 are presented in Figures 1-4.

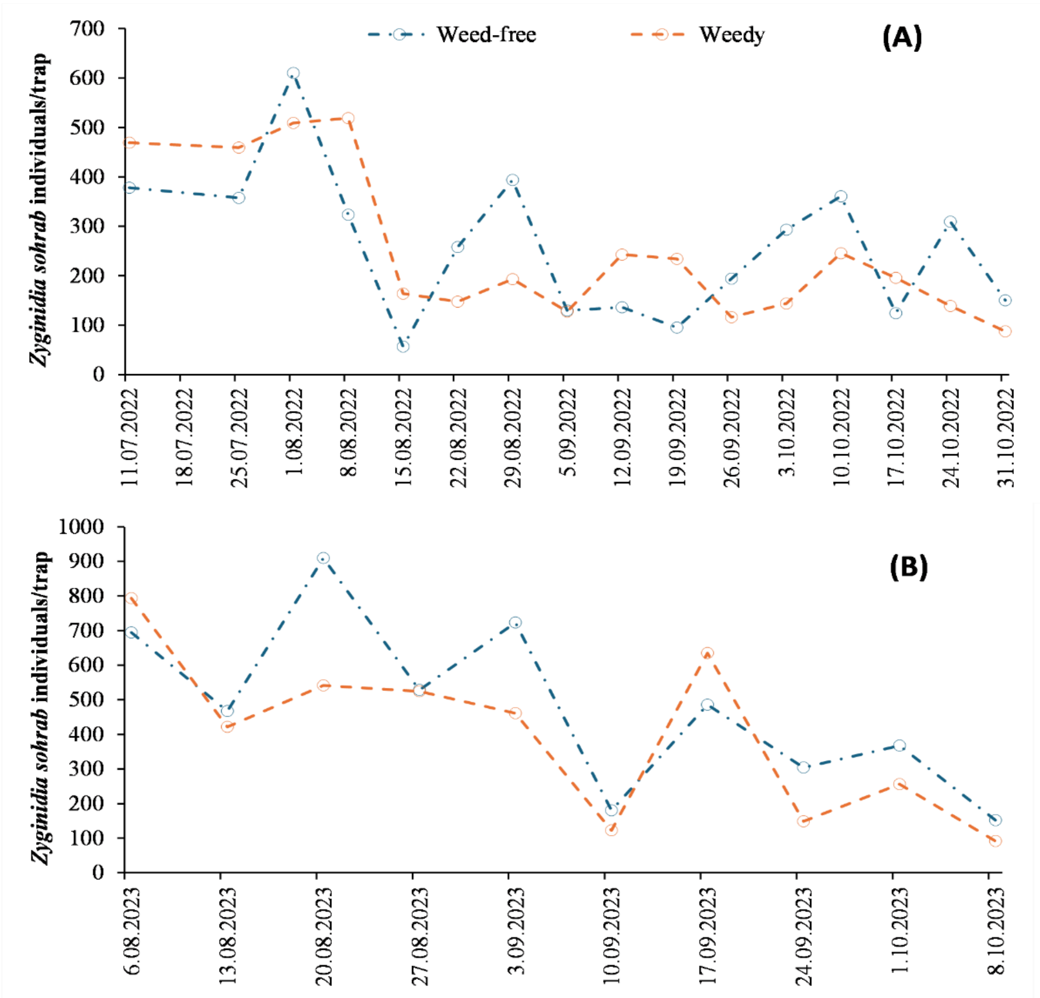

Figure 1. The influence of weed infestation on population density of *Zyginidia sohrab* in second crop maize during 2022 (A) and 2023 (B).

A total of 469 and 378 *Z. sohrab* adults were trapped by yellow stick traps from weedy and weed-free treatments, respectively during the second week of July 2022. The population density in weedy treatment was significantly higher than weed-free treatment until the third week after hanging of traps (August 1, 2022). Afterwards, higher population density of *Z. sohrab* was recorded in weed-free treatment than weedy plots. Population density of *Z. sohrab* in weed-free plots was 243 and 234.3 adults/trap, respectively during the second and third weeks of September (12.09.2022-19.09.2022). However, the density in weedy plots was 136 and 95.3 adults/trap during the second and third weeks, respectively. Subsequently, higher *Z. sohrab* density was noted in weed-free treatments than in weedy plots (Figure 1).

The monitoring started in early August during 2023 because the trials were established later than 2022. A total of 793 and 694 *Z. sohrab* individuals were recorded from weedy and weed-free treatments during first week. Afterwards, higher *Z. sohrab* was noted in weed-free plots than weedy plots. A higher number of *Z. sohrab* individuals were recorded in weedy treatments only in mid-September (17.09.2023) than weed-free treatment (Figure 1).

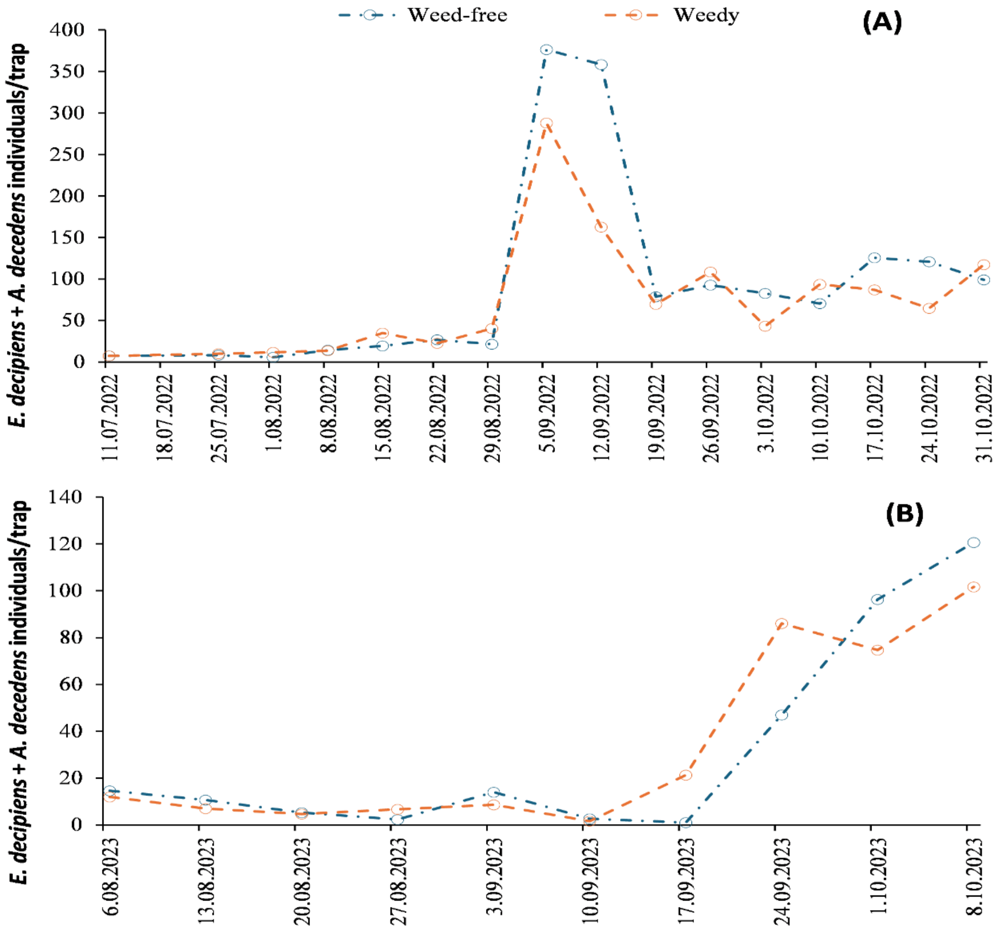

Figure 2. The influence of weed infestation on population density of *Empoasca decipiens* & *Asymmetrasca decedens* complex in second crop maize during 2022 (A) and 2023 (B)

A similar number of *E. decipiens* & *A. decedens* adults (7 individuals per trap) were observed in the traps placed in weedy and weed-free plots during second week of July (11.07.2022). Afterwards, the population density in weedy plots was significantly higher than in weed-free plots until the third week after trap installation (01.08.2022). The population of *E. decipiens* & *A. decedens* in the weed-free plots during the 7^{th}, 11^{th}, 13^{th}, and 16^{th} weeks was 40, 108, 93, and 117 adults/trap, respectively, while the density in weedy plots was 21, 92, 70, and 99 adults/trap, respectively during the same weeks (Figure 2).

The population density of *E. decipiens* & *A. decedens* was lower in 2023 compared with 2022. On average, 15 individuals were captured in the traps from the weedy treatments, while 12 individuals of *E. decipiens* and *A. decedens* were found in the traps from the weed-free plots. Subsequently, population density of *E. decipiens* & *A. decedens* was greater in weed-free compared to weedy treatment. A greater number of *E. decipiens* & *A. decedens* individuals were found in weed-free treatments than weedy treatments during first and second weeks of October (Figure 2).

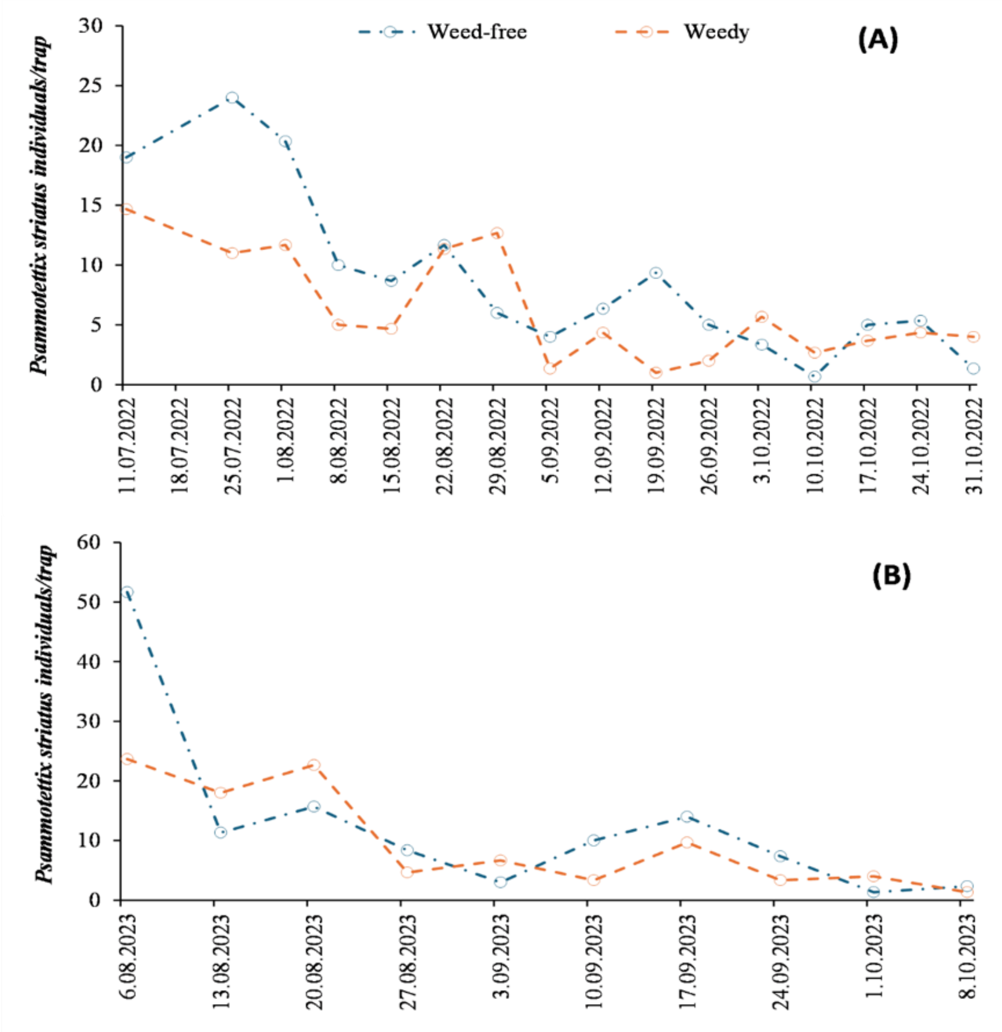

Figure 3. The influence of weed infestation on population density of *Psammotettix striatus* in second crop maize during the 2022 (A) and 2023 (B)

An average of 19 *P. striatus* adults were recorded from weed-free treatments, while 15 *P. striatus* adults were recorded from weedy treatments during the second week of July in 2022. Afterwards, the population density in the weed-free plots was significantly higher than weedy plots until the 7th week (22.08.2022). The population density of *P. striatus* in weedy treatment (13 adults/trap) on August 29,2022 was higher than weed-free treatment (6 adults/trap). Likewise, population density of *P. striatus* in the weedy plots was 6 and 3 adults/trap, respectively, while it was 3 and 1 adults/trap in weed-free plots during the first and second weeks of October (03.10.2022-10.10.2022).

Population density of *P. striatus* in 2023 was higher than 2022. However, its density was considerably lower than other leafhopper species. A total 52 adult *P. striatus* were recorded from the weed-free treatments during the first week (6.8.2023), while 24 adults were determined in weedy plots. Subequently, *P. striatus* density was higher in weed-free plots than weedy during 4th, 6th, 7th, 8th, and 10th sampling weeks (Figure 3).

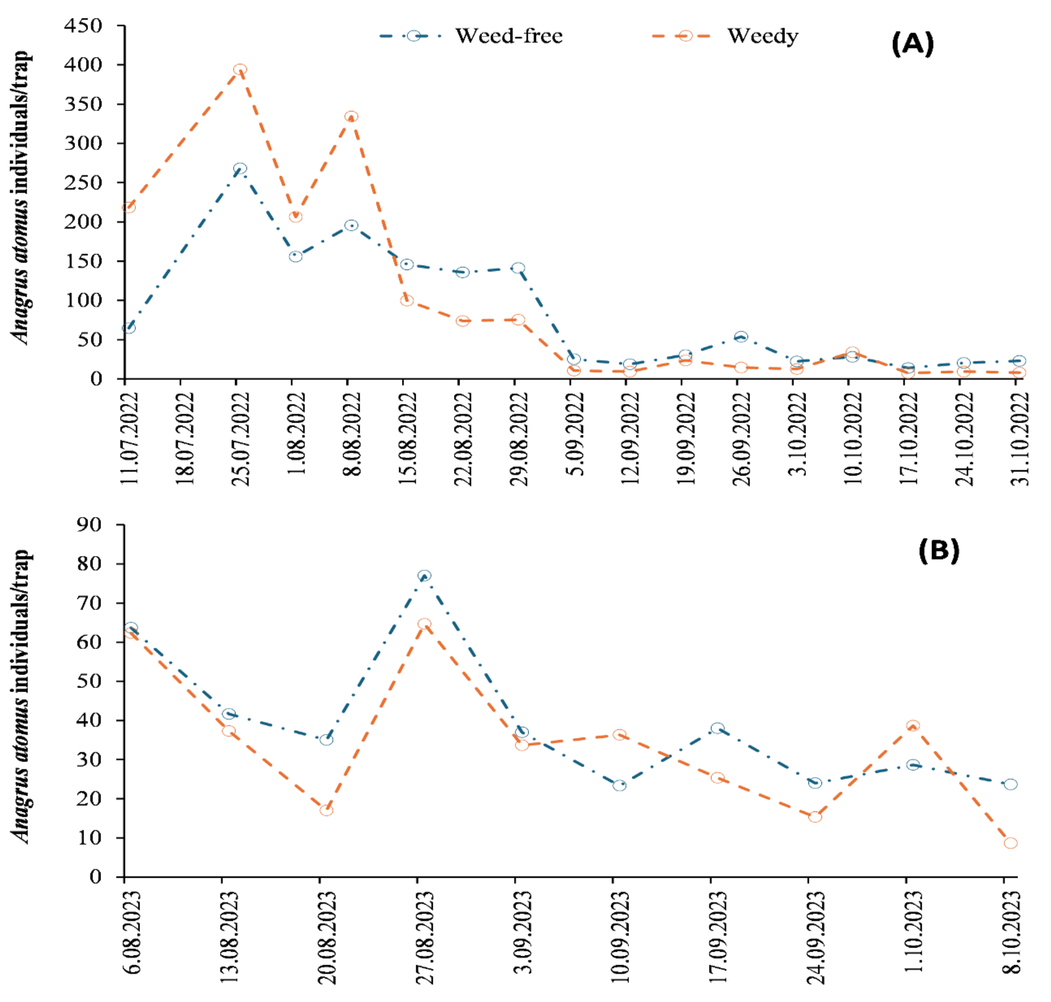

Figure 4. The influence of weed infestation on population density of *Anagrus atomus* in second crop maize during 2022 (A) and 2023 (B)

An average of 218 *A. atomus* adults were recorded from weedy treatment, whereas 65 *A. atomus* adults were recorded from the weed-free treatments during second week of July 2022. Population density of *A. atomus* in weedy plots was substantially greater than weed-free plots during 5th week (August 15, 2022). Afterwards, population density was higher in weed-free treatments than in weedy treatments except for the 13th week (10.10.2022) (Figure 4). A total 4596 *A. atomus* adults were recorded from weedy treatment, while 4030 adults were noted from weed-free treatment during the whole study period.

Unlike 2022, 62 individuals were recorded from weedy treatment during first week after trap installation in 2023, while 64 *A. atomus* individuals were noted from weed-free treatments. Subsequently, *A. atomus* density was higher in the weedy plots than in the weed-free plots. A higher density was recorded in weedy treatment than weed-free treatment only at the beginning of October (01.10.2023) (Figure 4). A total of 1018 *A. atomus* adults were noted from weedy treatment, while 1176 adults were recorded from weed-free treatment during 2023.

The number of leafhopper eggs parasitized by *A. atomus* sampled from maize and *S. halepense* leaves within the weedy and weed-free treatments are presented in Figure 5.

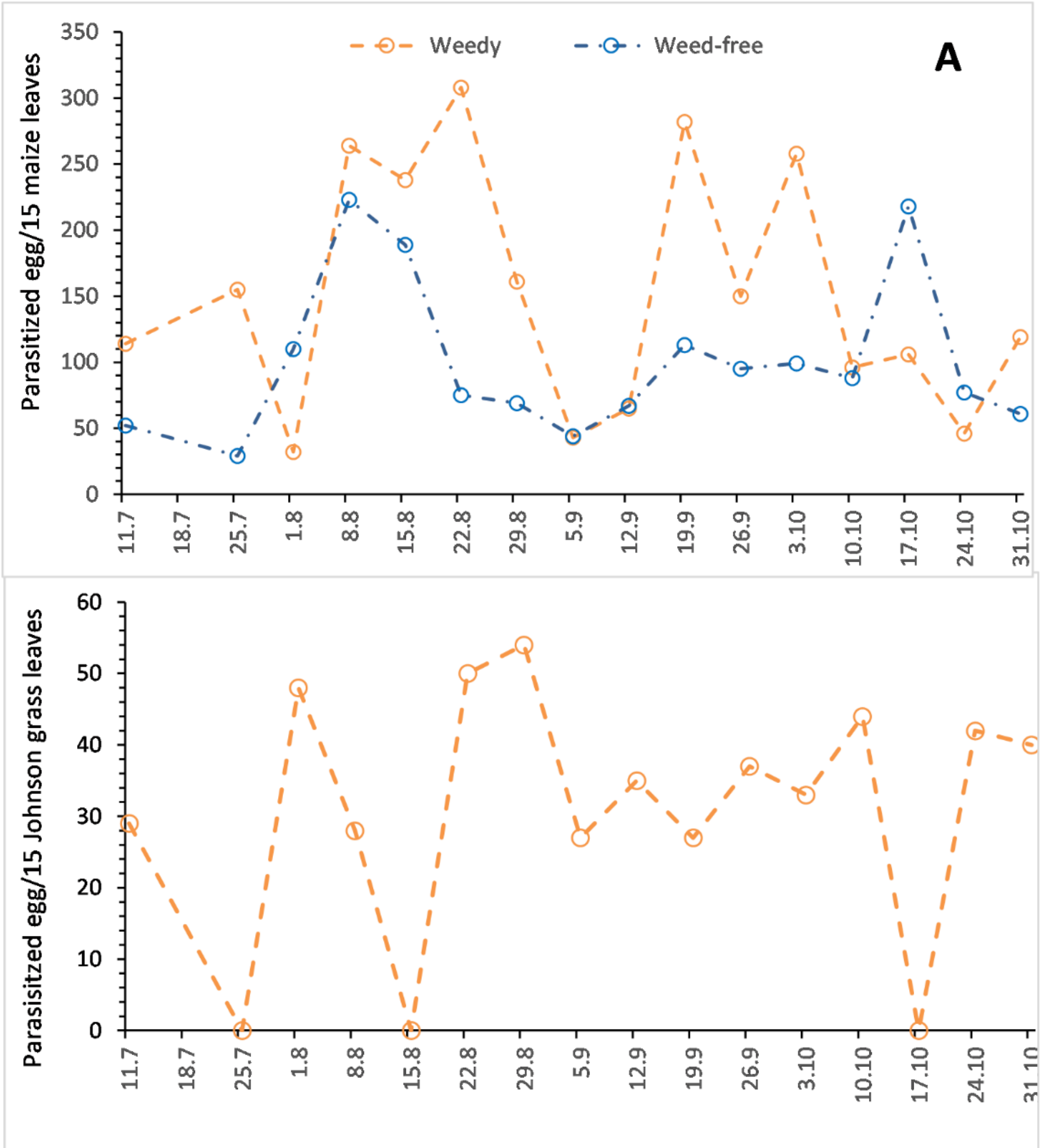

Figure 5. The influence of weed infestation on number of parasitized leafhopper eggs by *Anagrus atomus* in second crop maize in weedy and weed free treatments (A), and the number of parasitized leafhopper eggs in *Sorghum halepense* leaves (B) during 2022

A total of 114 parasitized eggs (with an average of 7.6 parasitized eggs per leaf) were identified in the weedy treatments in the first week, whereas 52 eggs (with an average of 3.5 parasitized eggs per leaf) were observed from weed-free treatments. The number of parasitized leafhopper eggs in the weedy treatments was generally higher than in the weed-free plots. However, a higher number of leafhopper eggs parasitized by *A. atomus* were recorded in the weed-free treatments compared to the weedy plots during the first week of August 14th week close to harvest (17.10.2022) and 15th week (24.10.2022) (Figure 5A).

A significant number of parasitized leafhopper eggs were determined from *S. halepense* leaves in weedy treatment. A total of 29 parasitized eggs were recorded in the leaves of *S. halepense* in the first week of study, which increased in the following weeks. No parasitized leafhopper eggs were found in leaf samples collected in the second, third, and fifth weeks of counting (Figure 5B). A total of 494 parasitized eggs were recorded during the study. A total of 2437 *A. atomus* individuals were detected from in the weedy treatments, whereas this number was 1609 in weed-free plots.

The analysis of variance table for the weekly population densities of leafhoppers and *A. atomus* in both trial field is provided in Table 1.

Table 1. Analysis of variance (p values) for the effect of weed infestation (weedy and weed-free) on population densities of *Zyginidia sohrab, Empoasca decipiens & Asymmetrasca decedens* and *Psammotettix striatus* in second crop maize.

Weeks	*Zyginidia sohrab*		*E. decipiens & A. decedens*		*Psammotettix striatus*		*Anagrus atomus*	
	2022	2023	2022	2023	2022	2023	2022	2023
				P değeri				
Hafta 1	0.38	0.66	1.00	0.39	0.71	0.05	0.03	0.97
Hafta 2	0.10	0.58	0.47	0.48	0.10	0.21	0.26	0.51
Hafta 3	0.44	0.16	0.03*	0.68	0.03*	0.23	0.22	0.03*
Hafta 4	0.17	0.99	0.71	0.13	0.08	0.06	0.05	0.62
Hafta 5	0.00*	0.12	0.00*	0.52	0.02*	0.08	0.28	0.59
Hafta 6	0.03*	0.30	0.35	0.47	0.96	0.08	0.06	0.12
Hafta 7	0.03*	0.48	0.35	0.00*	0.21	0.24	0.03*	0.03*
Hafta 8	0.97	0.13	0.15	0.00**	0.16	0.13	0.04*	0.06
Hafta 9	0.24	0.34	0.04*	0.34	0.49	0.12	0.01	0.23
Hafta 10	0.10	0.02*	0.61	0.56	0.00*	0.51	0.22	0.03*
Hafta 11	0.19	-	0.76	-	0.02*	-	0.01*	0.97
Hafta 12	0.14	-	0.00*	-	0.32	-	0.04*	-
Hafta 13	0.31	-	0.28	-	0.10	-	0.47	-
Hafta 14	0.40	-	0.33	-	0.33	-	0.01*	-
Hafta 15	0.06	-	0.02*	-	0.65	-	0.00*	-
Hafta 16	0.02*	-	0.56	-	0.04*	-	0.02*	-
Total	0.52	0.27	0.01	0.73	0.04	0.05	0.08	0.08

*The differences between weedy and weed-free treatmens were statistically significant during the relevant sampling week ($P < 0.05$)

**Sampling weeks started from 11 July and 16 August during 2022 and 2023, respectively

Statistically significant variations were recorded in the numbers of leafhoppers and the parasitoid recorded from weedy and weed-free treatments during different sampling weeks. *Zyginida sohrab* had a notable population density during the 5th, 6th, 7th, and 16th weeks of 2022. However, non-significant differences were recorded between weedy and weed-free treatments for population density in other weeks. No statistical difference was observed during all weeks except for the last week of 2023. A similar data was observed for other leafhopper species and *A. atomus*.

Table 2 presents the total number of leafhopper and parasitoid individuals recorded from weedy and weed-free treatments during 2022 and 2023.

Table 2. The influence of weed infestation (weedy and weed-free) on population densities of Zyginidia sohrab, Empoasca decipiens & Asymmetrasca decedens, and Psammotettix striatus in second crop maize during 2022 and 2023

Weed status	2022	2023
	Zyginidia sohrab	
Weed-free	4172 **a***	4811 **a**
Weedy	3994 **a**	3996 **a**
	Empoasca decipiens* & *Asymmetrasca decedens	
Weed-free	1508 **a**	324 **a**
Weedy	1175 **b**	315 **a**
	Psammotettix striatus	
Weed-free	140 **a**	125 **a**
Weedy	100 **b**	97 **a**
	Anagrus atomus	
Weed-free	1343 **a**	392 **a**
Weedy	1532 **a**	339 **a**

* The means followed by similar letters within a column do not differ significantly from each other (P>0.05).

The study revealed that weed infestation did not have a significant impact on the population density of *Z. sohrab* in both years (Table 2). The presence of weeds was associated with a notable increase in the population density of *E. decipiens* & *A. decedens* species. However, it was documented that there was no notable impact observed in 2023 (Table 2). Similarly, more *P. striatus* individuals were recorded from weedy treatments than weed-free treatment in 2022. Statistical analysis also revealed that *A. atomus* belonged to the same group in both years, and that the density and type of weeds did not have a major role in increasing the parasitoid's population.

The study findings indicated that weed infestation in second crop maize did not lead to an increase in the population of signifcant harmful leafhoppers. Contrastingly, Mutlu et al. (2016) observed that weeds increased the population of cicadellids in rice fields as 71.4% of individuals were recorded from weedy fields, whereas 28.6% were noted from weed-free fields. On the other hand, Paradell et al. (2014) reported that weeds resulted in significantly higher leafhopper species from rice fields. Similar studies in different crops have reported that certain weeds (such as Johnson grass, purslane, nutgrass and common cocklebur) significantly increase the population of Cicadellidae, indicating the necessity of weed control (Andow, 1992; Oloumi-Sadeghi et al., 1989; Margues et al., 2012; Mutlu and Sertkaya, 2015a). In contrast, Sadeghi et al. (1989) noted that winter herbicide application in potatoes had no effect on the density of the potato leafhopper, *Empoasca fabae* (Harris), whereas summer herbicide application increased the density of *E. fabae*.

The direct interaction between leafhoppers and weed infestation has not been investigated in these studies, but some studies examined the interactions between weeds, arthropod pests, and their natural enemies in managed ecosystems (Way 1977; Perrin and Phillips, 1978; Altieri and Whitcomb, 1979; Norris and Kogan, 2000). It is well-known that a region's weed species and population not only serve as food sources, shelter, overwintering grounds, and reproductive sites for phytophagous and other insects, but also enhance their population (Southwood and Way, 1970; Altieri, 1999). Nevertheless, weed-free plots had a lower population density of the most widespread species, i.e., *Z. sohrab* in the current study.

It is thought that adult females of *Z. sohrab* feeding on *S. halepense* deposit eggs into the tissue of *S. halepense* leaves and subsequently these eggs are parasitized by *A. atomus* which suppress *Z. sohrab* density. Mutlu and Sertkaya (2015a) have stated that both the adults and nymphs of *Z. sohrab* intensively feed and lay eggs in *S. halepense* leaves, which increases population density of *Z. sohrab*. Additionally, *Z. sohrab* eggs were parasitized by *A. atomus* on *S. halepense* leaves; however, parasitism rate was not reported. In the current study, a significant number of *Z. sohrab* eggs parasitized by *A. atomus* were found within the leaf tissue of *S. halepense* sampled from weedy treatment. It is thought that the population density of *Z. sohrab* is higher in the weedy plots than in weed-free plots. However, parasitoid suppresses leafhoppers population in weedy plots. The total numbers *Z. sohrab* individuals recorded on weedy and weed-free treatments were quite similar. Nevertheless, *A. atomus* density recorded weedy treatment and parasitoid obtained from *S. halepense* was significantly higher than weed-free plots. The parasitoid has a negative impact on the *Z. sohrab* population in weedy plots because it parasitizes many eggs, where the population of *Z. sohrab* is high. Supporting our hypothesis, Blaix et al. (2018) stated that the most common contribution of weeds to reducing pest insect populations occurs by providing resources to natural enemies in agricultural areas.

Several studies have demonstrated that the egg density of leafhoppers in a crop has a significant impact on parasitism rate, with higher egg densities leading to increased parasitism rates (Segoli and Rosenheim, 2013; Mutlu and Sertkaya, 2015b; Li et al., 2018; Torres-Moreno and Moya-Raygoza, 2020). According to reports, *A. atomus* attempts to suppress *Z. sohrab* by parasitizing its eggs at a high rate (50.2% to 93.7%) in second crop maize (Mutlu and Sertkaya, 2015b). Parasitization of eggs within the leaf tissue of *S. halepense* by *A. atomus* reduced the population density of *Z. sohrab*, even though an increase in the population of *Z. sohrab* adults feeding and laying eggs on *S. halepense* was expected in the weedy treatment in the current study. Andow (1983) has suggested that the diversity and density of plant cover in agricultural ecosystems tend to increase populations of herbivorous insects and their natural enemies. It has been mentioned that weeds a greater threat to harmful insect species than beneficial ones and that weeds cannot be completely eradicated (Schellhorn and Sork, 1997).

Similar results have been obtained in other leafhopper species besides *Z. sohrab*. A higher density of *E. decipiens* & *A. decedens* complex was recorded from weed-free treatments in the first year. These species are generally reported to feed on cocklebur (*Xanthium strumarium* L.), a weed commonly found within and on the edges of fields, apart from maize and cotton (Mutlu et al., 2008a). However, in this study, the absence of cocklebur in the weedy treatment has strengthened the assumption that *E. decipiens* & *A. decedens* complex density was higher in weed-free plots. *Psammotettix striatus* has been recorded as having the lowest population density on the maize plants in the current study. Previous studies conducted in different areas revealed that this species exhibits a comparably small population in maize fields when compared to other leafhopper species (Mutlu et al., 2008a; Akmeşe and Sertkaya, 2021; Atmaca et al., 2021; Baran Yazıcı et al., 2023). Additionally, it has been reported that *P. striatus* carries some phytoplasma diseases as well as Wheat Blue Dwarf Virus (WBD) and Russian Mosaic Virus of Winter Wheat (WWRMV) in wheat (Mutlu et al., 2023). It is known that this species is generally abundant in cotton fields and migrates to second-crop maize later (Mutlu et al., 2008a). Therefore, the population of *P. striatus* was very low as in 2022, and weed infestation had a positive effect on its population density.

Although direct relationship between leafhoppers and weed infestation remains elusive, it is believed that weeds and other environmental factors may indirectly influence the density and distribution of leafhoppers and their natural enemies in agricultural ecosystems. Even though the association of weeds with phytophagous insects may pose a disadvantage in terms of pest management, it is essential not to overlook the significant role of weeds in preserving biodiversity. Therefore, it is believed that identifying phytophagous insect species feeding on weeds both within and around crop fields, along with their natural enemies, and effective weed management strategies are essential for maintaining pest control and promoting biological control in agricultural ecosystems.

Conclusions

The study concludes that weed infestation (especially johnsongrass) in second-crop maize fields had non-significant effect on population densities of harmful leafhoppers. It was noted that the most abundant species (*Z. sohrab*) has a lower density in the weedy treatment. Furthermore, *Z. sohrab* eggs are effectively parasitized by *A. atomus* in weed treatment. As a result, this leads to a decrease in the population of leafhoppers in the weedy treatment. The densities of *E. decipiens* & *A. decedens* and *P. striatus* varied between years, and higher densities were recorded in weedy treatment during 2022. Besides, diversity of weed species have a positive effect on the population of *A. atomus*, and parasitoid population was higher in weedy treatment than weed-free plots. Understanding the complex interactions between weeds and leafhoppers is important for developing effective pest management strategies. It is concluded that weed control should be designed considering the weeds providing food, shelter, alternative prey, and hosts for beneficial insects.

Declarations

This study is part of the doctoral dissertation of the first author. The authors would like to thank Mr. Beşir YAZAR, a producer from Büyükördek village in Şanlıurfa province, for providing the study area and for his valuable support.

Conflict of Interest

The authors declare that there is no conflict of interest regarding the subject of this study.

Author Contributions

Hasan Tunaz and Çetin Mutlu conceived the idea and designed the experiments, Çetin Mutlu and Emine Kaplan Yavuz conducted the experiments and collected data. Çetin Mutlu analyzed the data and wrote the initial draft of the manuscript. Hasan Tunaz and Emine Kaplan Yavuz edited and approved the final draft.

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