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Weed flora in forage maize fields as an attraction for entomophagous insects

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Abstract

Background Phytosanitary problems, particularly insect pests, frequently threaten forage maize crops. However, spontaneous weed flora associated with these crops may provide key ecological functions by hosting entomophagous insects that contribute to biological pest control. This study aimed to evaluate the role of six weed species flowers—*Amaranthus palmeri* S. Watson, *Datura quercifolia* Kunth, *Solanum elaeagnifolium* Cav. *Helianthus laciniatus* A. Gray, *Setaria adhaerens* (Forssk.), and *Verbesina encelioides* (Cav.) Benth. & Hook—in attracting predatory and parasitoid insects within maize agroecosystems in Durango, Mexico.

Results A total of 2,364 insects were collected, of which 404 (17.08%) were identified as entomophagous insects, comprising 211 predators and 193 parasitoids. The predators genera and species identified were: *Hippodamia* Dejean, 1837; *Scymnus* Kugelann, 1794 (Coleoptera: Coccinellidae); *Toxomerus* Macquart, 1855 and *Allograpta* Osten Sacken, 1875 (Diptera: Syrphidae); *Chrysoperla* Steinmann, 1964 (Neuroptera: Chrysopidae); *Orius tristicolor* (White, 1879) and *Orius insidiosus* (Say, 1832) (Hemiptera: Anthocoridae); *Nabis* (Latreille, 1802) (Hemiptera: Nabidae); *Spanagonicus albofasciatus* (Reuter, 1907) (Miridae); *Geocoris uliginosus* (Say, 1831) (Lygaeidae); and *Zelus tetracanthus* Stål, 1862 (Reduviidae). While the genera and species of parasitoids were: *Lysiphlebus testaceipes* Cresson, 1880 (Braconidae); *Aphelinoidea* Girault, 1911; *Oligosita* Walker 1851, *Trichogramma* Westwood, 1833 and *Paracentrobia* Howard, 1897 (Trichogrammatidae); and *Eretmocerus* Haldeman 1850 (Aphelinidae). *A. palmeri* attracted the highest number of predators (150 specimens of *Orius tristicolor*), although it showed low diversity due to strong dominance by Anthocoridae (86.7%). In contrast, *D. quercifolia* and *V. encelioides* harboured the most diverse communities, with Shannon indices of 1.98 and 1.84 for parasitoids, respectively. Furthermore, *H. laciniatus* supported the highest abundance of parasitoids (64 individuals, 33% of total parasitoids), and, according to Generalized Linear Models ($p < 0.05$), this species exhibited significantly greater attraction than most other weed species.

Conclusions Certain weed species, particularly those from the Asteraceae family, offer critical resources that support diverse communities of natural enemies in maize systems. *H. laciniatus*, *D. quercifolia*, and *V. encelioides* showed strong potential to enhance conservation biological control in arid agroecosystems. Integrating selected weed species into pest management strategies not only helps stabilize arthropod populations but also inspires the promotion of sustainable agriculture in the region.

Keywords Predators, Parasitoids, Diversity, Weeds, Maize, Biological control

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Background

Maize (*Zea mays* L.) is a crucial global crop for both food security and economic development. In the 2023–2024 cycle, global production reached a record 1,228.1 million tons, with the United States being the largest producer with 31.7%, followed by China (23.5%) and Brazil (9.9%). Mexico ranks eighth, contributing 1.9% of production and 3.9% of consumption worldwide. Corn serves multiple roles, including human and industrial consumption, as well as animal feed, highlighting its strategic relevance (Fideicomisos Instituidos en Relación con la Agricultura [FIRA], 2024). Regionally, Mexico's Laguna area, spanning Coahuila and Durango states, is a key dairy basin relying on forage crops like maize. In 2023, this region harvested 47,637 hectares of maize, producing over 2 million tons worth around 2.47 billion Mexican pesos (El Siglo de Torreón 2023). Maize crops in this region are affected by various phytosanitary challenges, such as diseases, insect pests, and weeds. Key insect pests include *Spodoptera frugiperda* (J.E. Smith, 1797) (fall armyworm) (Lepidoptera: Noctuidae), *Helicoverpa zea* (Boddie, 1850) (corn earworm) (Lepidoptera: Noctuidae), *Diatraea* Guiling, 1828 (stem borers) (Lepidoptera: Crambidae), and others, which collectively impose significant constraints on crop productivity (Hernández-Trejo et al. 2019).

Weeds cause direct production losses by competing for nutrients, water, and light; however, they also serve a vital ecological role by promoting the diversity and persistence of natural enemies that regulate pest populations. Biological control particularly that of conservation, promotes the activity, survival, and reproduction of indigenous natural enemies by maintaining or introducing weed species that provide essential resources such as nectar and pollen (Montoya and Toledo 2020). Although mechanized agriculture often demands simplification of plant diversity, strategic retention of key weed species within or around crops can enhance pest regulation, as demonstrated in various agroecosystems (Hatt and Döring 2024).

Research has shown that wild plant flowers within and adjacent to crop fields supply pollen and nectar critical for natural enemies, with flower strips being one effective method to augment these resources (Lundin et al. 2023). Studies on parasitoid Hymenoptera associated with vegetation cover, such as those conducted by Wibowo et al. (2023) reveal that diverse weed species—including invasive taxa like *Ageratum conyzoides* L. 1753 (Asterales: Asteraceae), *Bidens pilosa* L. 1753 (Asterales: Asteraceae) and *Lantana camara* L. 1753 (Lamiales: Verbenaceae)—can support parasitoid communities by providing food and habitat resources. Despite the recognized potential of natural enemies in biological control programs in Mexico, most existing studies are of a general scope and fail to address the specific weed species commonly

associated with forage maize in the semi-arid regions of northern Mexico (López et al. 2004). There is limited information on entomophagous insects associated with locally dominant weeds such as *Amaranthus palmeri* S. Watson, *Datura quercifolia* Kunth, *Solanum elaeagnifolium* Cav, *Helianthus laciniatus* A. Gray, *Setaria adhaerens* (Forssk.) Chiov, and *Verbesina encelioides* (Cav.) Benth. & Hook influences the attraction of natural enemies in maize fields. This gap is relevant because maize is a strategic crop in the Comarca Lagunera, where pest outbreaks frequently compromise productivity.

In this context, the present study aims to identify the entomophagous insects associated with weed species present in forage maize in the Comarca Lagunera region, thereby contributing to the development of conservation biological control strategies. Understanding these plant-insect interactions is crucial for optimizing integrated pest management (IPM). Weeds serve as critical sources of green biomass and habitat during crop dormancy, supporting arthropod survival and helping maintain ecosystem stability (Norris and Kogan 2000).

Methods

Study site

The study was carried out in 2021 at Rancho del Carmen, a property of the Universidad Autónoma Chapingo (UACH), Unidad Regional Universitaria de Zonas Áridas, located in Bermejillo, Durango, Mexico (coordinates 25.896316° N, 103.591838° W) at an altitude of 1120 m above mean sea level. According to the Köppen classification, modified for Mexico, this area has an arid, semi-warm climate with an annual average rainfall of 264 mm and extreme temperatures ranging from an average minimum of 3.9 °C to an average high of 37.41 °C (García 1973; CONANP 2006).

Field method

During the summer, an experimental plot of 0.5 ha was established with forage maize (*Zea mays*), no chemical fertilizers or pesticides were used during the crop management, allowing natural weed development. During the reproductive phase of maize (R1 to R5), the six most abundant weed species in their flowering stage were selected for insect sampling. For this study, a sampling unit was defined as all insects collected from the flowers of three randomly chosen weed plants of the same species, with each set of three plants considered one independent and equally probable sample from the available population in the study area. Adult specimens of insects were collected from each sample unit weekly over six weeks, using an entomological net. Collected specimens were killed in a lethal chamber with ethyl acetate and preserved in 70% ethanol within 250 ml containers.

Taxonomic identification

Taxonomic identification of collected insects was based on observation of the external morphology. Parasitoid insects of the order Hymenoptera were identified using dichotomous keys and bibliography from Gauld and Bolton (1988), Goulet and Huber (1993), Gibson et al. (1997), Wharton et al. (1998) and Bahena (2008). Family, genus and species of predatory insects were determined using taxonomical keys from Garland (1985), Gordon (1985), Flint and Dreistadt (1998), and New (2001). The collected data was recorded in an Excel spreadsheet.

Data analysis

Relative abundance was calculated as the percentage of each insect family relative to the overall number of predatory and parasitoid insects. Shannon–Wiener Diversity Index (H') and Simpson's Diversity Index (D) were calculated to measure the diversity and equity of insect families. Margalef Richness Index was used to highlight the weed species rich in insect families. All indices were computed using the free software PAST version 4.17 (Øyvind et al. 2020).

All statistical analyses were performed using R statistical software version 4.4.0. (R Core Team 2024). A

Generalized Linear Model (GLM) was used to assess which weed types were best at attracting entomophagous insects. Early data analysis revealed over dispersion, thus a negative Binomial Distribution was used. The model included weed species as a fixed effect since they were the key element of interest. The sample week was included as a random factor effect to account for the repeated measures sampling design (weekly sampling over six weeks on the same sites but no individual plant identification). The GLM was fitted using the lme4 package (Bates et al. 2015). Following model fit, a post-hoc Turkey pairwise test was performed to find specific differences in insect attraction, with a significance level of 0.05. These comparisons were made using the emmeans package (Lenth 2025).

Results

The predominant weed species were *Amaranthus palmeri* S. Watson, *Datura quercifolia* Kunth, *Solanum elaeagnifolium* Cav, *Helianthus laciniatus* A. Gray, *Setaria adhaerens* (Forssk) Chiov, and *Verbesina encelioides* (Cav.) Benth. & Hook (Fig. 1). The total number of insects collected was 2,364. Our interest focused on entomophagous insects, which accounted for 17.08% (404) (Table 1).

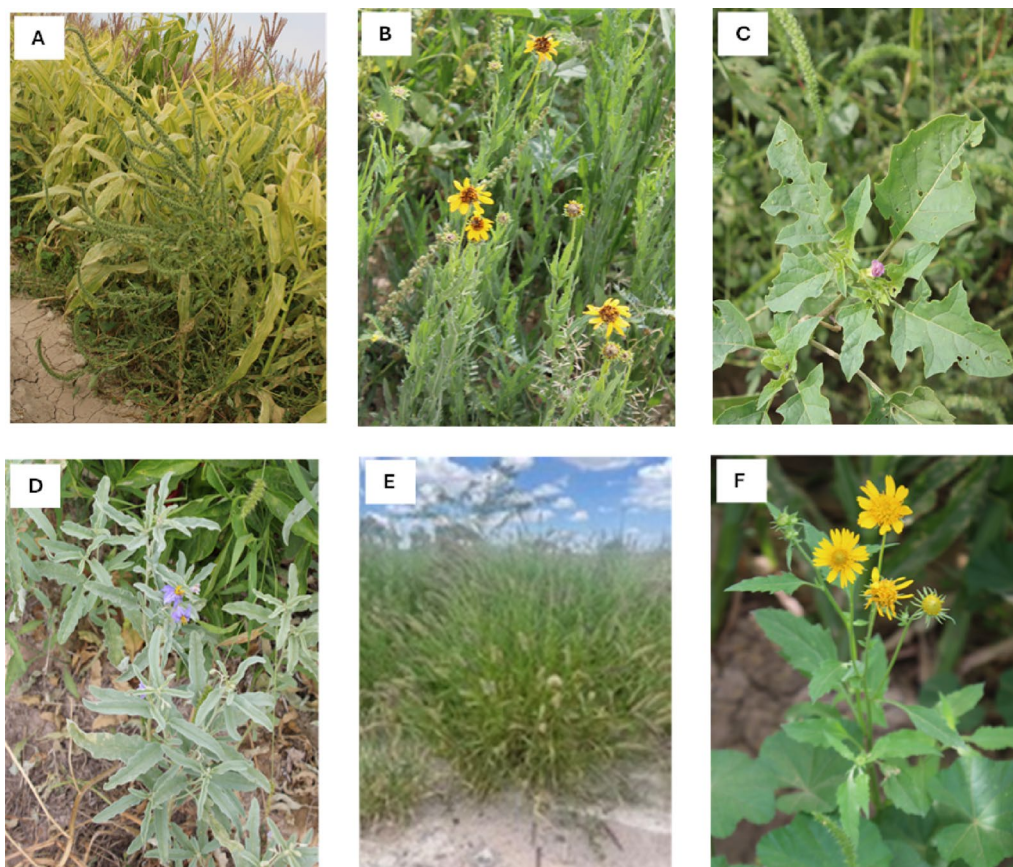


Fig. 1 Weed species associated with forage maize. **A:** *Amaranthus palmeri*; **B:** *Helianthus laciniatus*; **C:** *Solanum elaeagnifolium*; **D:** *Datura quercifolia*; **E:** *Setaria adhaerens*; **F:** *Verbesina encelioides*.

Table 1 Insects collected from the flowers of six weeds species over six weeks

Species	Weeks						Total
	1	2	3	4	5	6	
<i>Amaranthus palmeri</i> S. Watson	20	79	27	154	125	71	476
<i>Datura quercifolia</i> Kunth	17	42	23	63	31	55	231
<i>Solanum elaeagnifolium</i> Cav.	49	99	106	72	168	47	541
<i>Helianthus laciniatus</i> A. Gray	67	51	105	54	103	53	433
<i>Verbesina encelioides</i> (Cav.) Benth. & Hook	26	59	19	48	40	21	213
<i>Setaria adhaerens</i> (Forssk.) Chiov	30	81	46	54	194	65	470
Total	209	411	326	445	661	312	2364

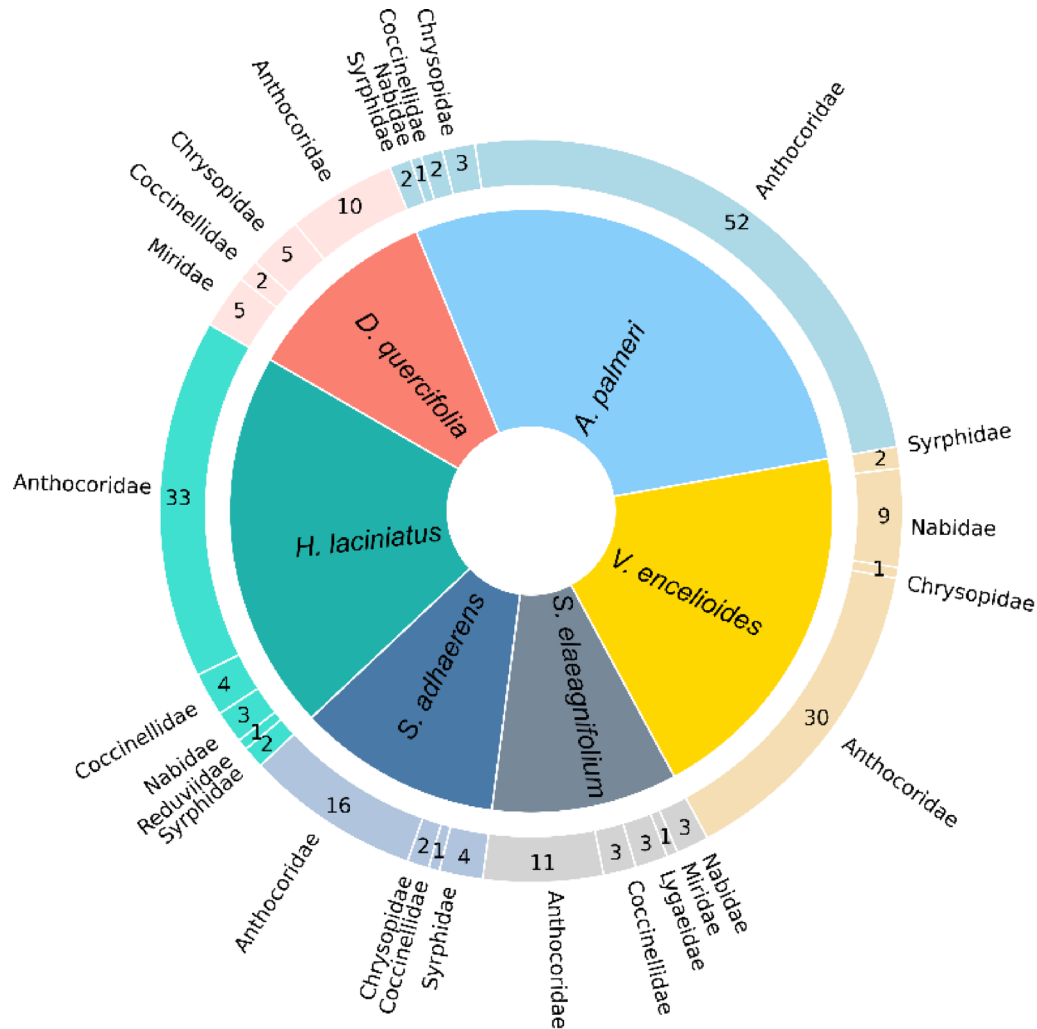


Fig. 2 Abundance of predatory families collected from the six weed species

Predatory insects

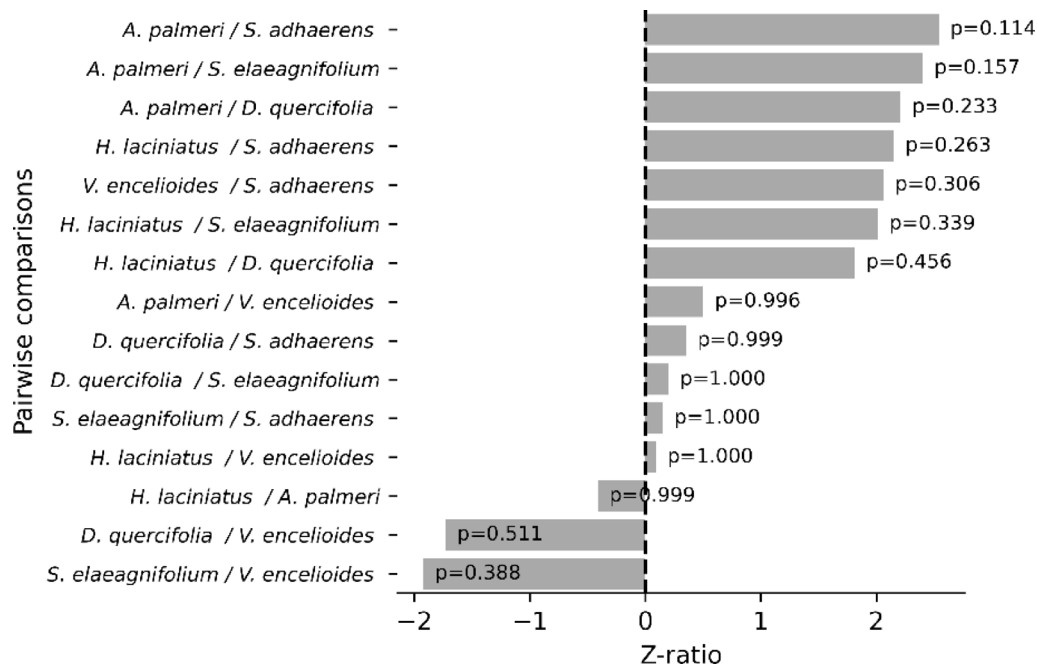
Out of the total number of entomophagous insects, 211 were predators. Eight families from four orders were identified: Diptera, Coleoptera, Hemiptera, and Neuroptera. Figure 2 depicts the families for each order and weed species.

Genus and species of predatory insects were identified. From the Coccinellidae family, ten specimens of *Hippodamia convergens* Guérin-Ménéville, 1842 were

obtained from all weed species, except in *V. encelioides*. In addition, *Scymnus* Kugelann was identified with two specimens, one on *D. quercifolia* and another on *S. elaeagnifolium*. From the Syrphidae family, the genus *Toxomerus* Macquart, 1855 was identified on *A. palmeri*, *H. laciniatus* and *S. elaeagnifolium*; and the genus *Allograpta* Osten Sacken, 1875 was only identified on *V. encelioides*. From the Chrysopidae family, twelve adults of *Chrysoperla carnea* (Stephens, 1836) were identified,

Table 2 Predatory insects' diversity indices

Indices	Weed species					
	<i>Amaranthus palmeri</i>	<i>Helianthus laciniatus</i>	<i>Datura quercifolia</i>	<i>Solanum elaeagnifolium</i>	<i>Setaria adhaerens</i>	<i>Verbesina encelioides</i>
Dominance	0.75	0.59	0.28	0.30	0.50	0.54
Simpson (1 - D)	0.24	0.40	0.71	0.69	0.49	0.45
Shannon (H)	0.60	0.88	1.31	1.41	0.97	0.84
Margalef	0.97	1.06	0.97	1.31	0.95	0.80

**Fig. 3** Statistical pairwise comparisons of weed species. Horizontal axis: Z-statistic values. Gray bars represent statistically no significant differences ($P > 0.05$)

with five specimens on *D. quercifolia*, three on *A. palmeri*, two on *S. adhaerens* and one of each on *S. elaeagnifolium* and *V. encelioides*.

Regarding the genus and species of Hemiptera (Fig. 2), Anthocoridae was present in all six weed species. From this family, the species *Orius tristicolor* (White, 1879) was identified with 150 specimens, and *Orius insidiosus* (Say, 1832) with two specimens. Other genus and species identified were *Nabis* (Latreille, 1802) (Nabidae); *Spanogonicus albofasciatus* (Reuter 1907) (Miridae); *Geocoris uliginosus* (Say, 1831) (Lygaeidae); and *Zelus tetracanthus* Stål, 1862 (Reduviidae).

Diversity indices. Shannon's diversity index indicated an increased diversity of predatory insect families in the weed *S. elaeagnifolium*. On the other hand, Simpson's diversity index reveals that *D. quercifolia* displays a greater diversity of insect families. Toward the Margalef index, *S. elaeagnifolium* achieved the highest scores. The highest values for dominance were recorded in *A.*

palmeri indicating that it is the species with the lowest insect diversity (Table 2).

The GLM analysis showed non-statistically significant differences among weed species in their ability to attract predatory insects (Fig. 3). This indicates that predator abundance was relatively similar across the six weeds evaluated.

Parasitoids insects

Of the total number of entomophagous insects, 193 were parasitoids from 12 families of the order Hymenoptera. Braconidae and Mymaridae had the most specimens (65 and 63, respectively), followed by Trichogrammatidae (26). The weeds with most of these insects were *H. laciniatus*, *S. adhaerens*, *A. palmeri*, and *S. elaeagnifolium* (Fig. 4).

In *H. laciniatus* 50 and 14 specimens were identified, corresponding to families Braconidae and Mymaridae, respectively. Among the Braconidae, the genus *Lysiphlebus* Foerster, 1862 was identified. The Mymaridae were

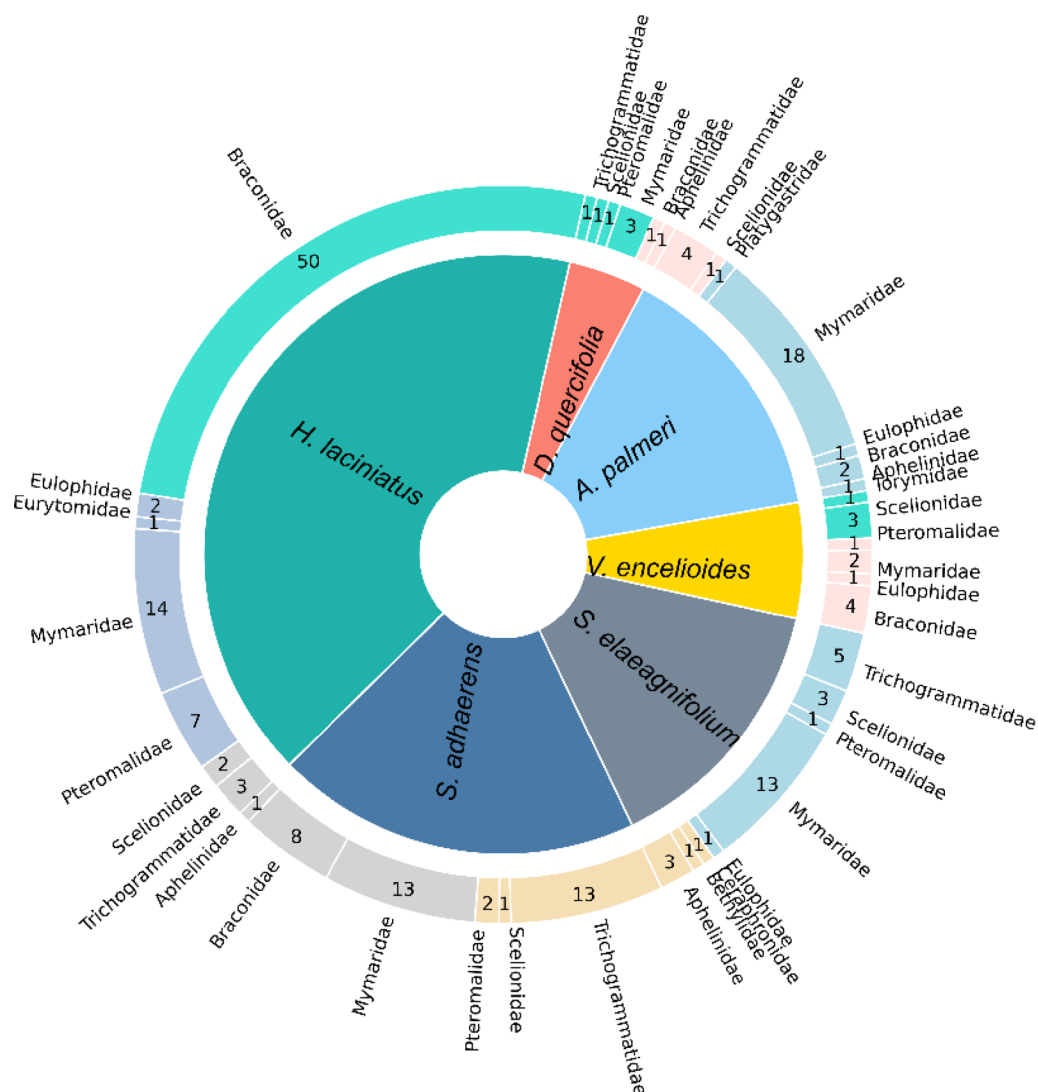


Fig. 4 Abundance of parasitoid families collected from the six weeds

Table 3 Parasitoid insects' diversity indices

Indices	Weed species					
	<i>Amaranthus palmeri</i>	<i>Helianthus laciniatus</i>	<i>Datura quercifolia</i>	<i>Solanum elaeagnifolium</i>	<i>Setaria adhaerens</i>	<i>Verbesina encelioides</i>
Dominance	0.42	0.44	0.11	0.25	0.26	0.15
Simpson (1–D)	0.58	0.56	0.89	0.75	0.74	0.85
Shannon (H)	1.33	1.22	1.98	1.74	1.47	1.84
Margalef	1.80	1.37	2.40	2.10	1.38	2.01

Diversity indices. The highest Shannon index for parasitoids was found in *D. quercifolia*, along with the highest values for Simpson's and Margalef's indices. The greatest levels of dominance were recorded in the weed *H. laciniatus* (Table 3).

The GLM test revealed that all comparisons of *H. laciniatus* to the other species were statistically significant. Post-hoc comparisons corroborated these findings except

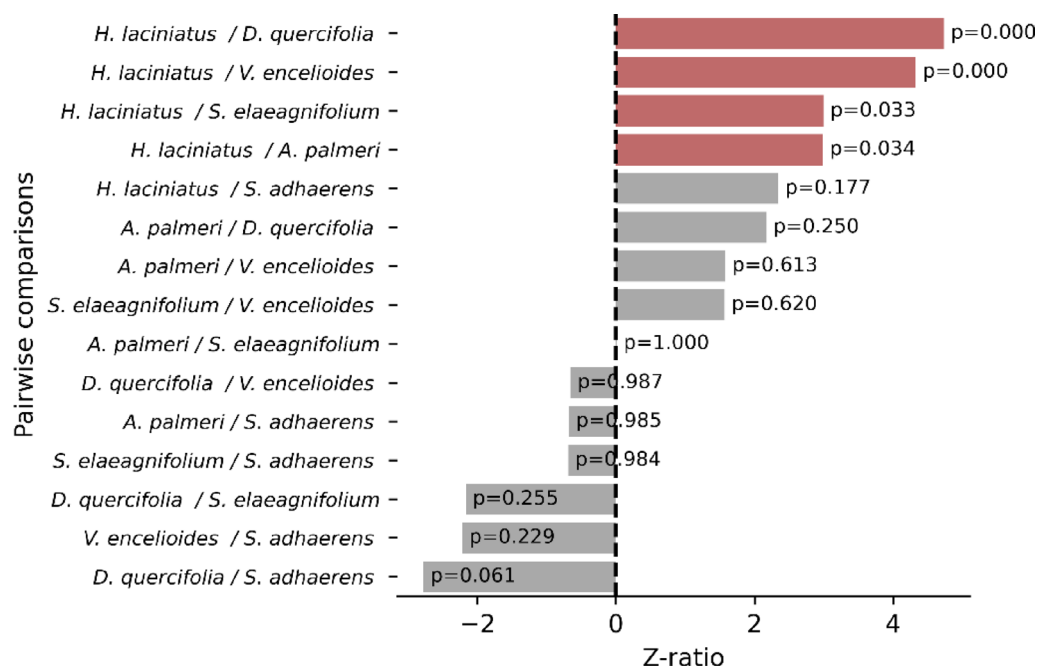


Fig. 5 Statistical pairwise comparisons of weed species. Horizontal axis: Z-statistic values. Gray bars represent statistically no significant differences. Red bars represent statistically significant differences ($P < 0.05$)

for *H. laciniatus* vs. *S. adhaerens* ($p = 0.176$). There were non-significant differences among the other weed species (Fig. 5). Based on these results, *H. laciniatus* was the weed species most likely to attract parasitoid insects in our study.

Discussion

A. palmeri exhibited the highest absolute abundance of predatory insects among the weed species analyzed, although it did not present the greatest insect diversity. This high abundance is primarily attributed to the specific dominance of the Anthocoridae family, which represented 86.66% of the predatory insects recorded in this species. While *A. palmeri* was notable for the number of predatory insects, it ranked third in parasitoid abundance—a position it shared with *S. elaeagnifolium*—and displayed the second highest level of parasitoid dominance. As a result, this weed showed the lowest values of diversity and evenness, as indicated by the Simpson and Shannon indices. Beyond its entomological associations, *A. palmeri* is recognized as a highly competitive species with crops, particularly in terms of nutrient, light, and water uptake. Nevertheless, if managed appropriately—through strategies such as limiting its spread, diversifying crop rotations, adjusting planting schedules and spacing, and incorporating cover crops (Oliveira et al. 2022)—*A. palmeri* could function as a reservoir or attractant for beneficial predatory insects. The success of this strategy depends on crop type, local predator and pest assemblages, landscape features, and management practices

(Cloyd 2020); therefore, the results of this study encourage further research into the use of *A. palmeri* as an attractant for beneficial insects.

In contrast, *V. encelioides* and *D. quercifolia* had low dominance and high Shannon and Simpson indices, indicating better diversity and evenness in the predatory insect composition. This diversity is related to the presence of multiple families of predators and a more balanced distribution of relative abundances. A similar pattern was observed in the parasitoid population associated with these weed species, particularly *D. quercifolia*, which had the highest values for both diversity and evenness. Furthermore, the Margalef index showed the greatest values for both species in relation to predators and parasitoids. These results suggest that *V. encelioides* and *D. quercifolia* offered a great structural heterogeneity and floral or extrafloral resources that favor the functional diversity of entomophagous insects. Therefore, these weeds could play an important role in strengthening biological control within agroecosystems (Salas-Araiza et al. 2023).

The study by James et al. (2018) highlights the importance of weeds belonging to the Asteraceae family as key habitats for beneficial arthropods, demonstrating that *Artemisia tridentata* harbors a high abundance of these organisms, 92% of which are parasitoid wasps. The richness and abundance of these arthropods increase significantly during the autumn flowering of *A. tridentata*. In line with these findings, two weed species belonging to this family were identified in the present study, suggesting

that *H. laciniatus* could be a particularly favorable habitat for parasitoids. Generalized Linear Models (GLM) comparisons indicated statistically significant differences in the attraction of parasitoid insects between *H. laciniatus* and the other weed species, except for the comparison to *S. adhaerens*. Non-significant differences were detected among the other weed species, positioning *H. laciniatus* as the species with the greatest potential to attract parasitoids in our study. This attraction may be related to several floral traits of *H. laciniatus*. Specifically, members of the *Helianthus* are characterized by composite inflorescences with numerous small, tubular florets, which provide easily accessible nectar and pollen to insects with short mouthparts, such as many hymenopteran parasitoids (Straser et al. 2024). Furthermore, the prolonged flowering period of *H. laciniatus* in semi-arid regions ensures a continuous resource supply during critical stages of parasitoid activity (Jocković et al. 2025). Additionally, the nectar composition in *Helianthus* species is typically rich in sugars, such as sucrose, glucose, and fructose, which enhance the longevity and fecundity of parasitoids (Jocković et al. 2025). Taken together, these functional traits may explain the high abundance of parasitoids recorded on *H. laciniatus* in our study.

On the other hand, although *V. encelioides* provided the greater contribution to the predator community, GLM indicated non-statistically significant differences in the attraction of predatory insects among the weed species tested. This finding is consistent with earlier research, which has found that the number of generalist predators may be less affected by specific variations across host plant species, especially when prey availability is homogeneous (Wan et al. 2020). The presence of a wide range of insect groups, including Hymenoptera, Diptera, Coleoptera, and Hemiptera, showed the complexities of plant-insect interactions in these systems, as well as the multifunctional role that weeds from the Asteraceae family may play in agroecosystems.

Conclusions

The findings of the study are significant, as they present a pioneering report on beneficial insects associated to six weeds species in the semi-arid region of Durango, Mexico, thereby expanding our knowledge and understanding of their distribution and potential use for biological control in various agricultural environments. The relative abundance of *A. palmeri* makes it an important weed for attracting predatory insects, especially those of the Anthoridae family, which prey on soft-bodied insects. On the other hand, our results reinforce the importance of conserving and managing wild Asteraceae, confirming and expanding the ecological importance of this family in attracting and maintaining entomophagous insect families, such as *H. laciniatus* and *V. encelioides*.

This establishes a precedent for the development of new projects, including proposals for crop management associated with these weed species, so contributing to biological control conservation programs and reducing the use of synthetic agrochemicals.

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Author contributions

F.G.G. study design and specimen identification. G.R.R. specimen collection. F.G.G., C.A.S.P. and M.M.E. literature review, writing, and manuscript revision. M.M.E. statistical analysis and graphs. C.A.S.P. diversity analysis.

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Data availability

No datasets were generated or analysed during the current study.

Declarations

Ethics approval and consent to participate

Not applicable.

Consent for publication

Not applicable.

Competing interests

The authors declare no competing interests.

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References

- Bahena JF (2008) Enemigos Naturales de las Plagas Agrícolas: Del maíz y otros cultivos. Libro técnico No 5. Instituto Nacional de Investigaciones Forestales, Agrícolas y Pecuarias (INIFAP). ISBN 978-607-425-013-8
- Bates D, Mächler M, Bolker B, Walker S (2015) Fitting linear mixed-effects models using lme4. *J Stat Softw* 67(1):1–48. <https://doi.org/10.18637/jss.v067.i01>
- Cloyd RA (2020) How effective is conservation biological control in regulating insect pest populations in organic crop production systems? *Insects* 11(11):744. <https://doi.org/10.3390/insects11110744>
- Programa de Conservación y Manejo. Reserva de la Biosfera Mapimí. Primera edición. SEMARNAT/CONANP, CONANP, México DF (2006) 178 pp. ISBN 968-817-762-8
- R Core Team (2024) R: A Language and Environment for Statistical Computing. R Foundation for Statistical Computing, Vienna, Austria. <https://www.R-project.org/>
- El Siglo de Torreón (2023) Resumen Económico 2023. Sector Agroalimentario. <http://www.elsiglodetorreon.com.mx/suplementos/?v=res/2023/01/#&gid=1&pid=26>. Accessed 10 Sep 2025
- Flint ML, Dreistadt SH (1998) Chap. 8: Predators of arthropods. In *Natural enemies handbook, the illustrated guide to biological pest control*, pp 79–116. University of California Press, Berkeley, Los Angeles and London. ISBN 978-1-879906-41-9
- García E (1973) Modificaciones al sistema de clasificación climática de Köppen (para Adaptarlo a Las condiciones de La República Mexicana), 2nd edn. Instituto de Geografía-UNAM, México, p 265
- Garland JA (1985) Identification of Chrysopidae in Canada, with bionomic notes (Neuroptera). *Can Entomol* 117(6):737–762. <https://doi.org/10.4039/Ent117737-6>
- Gauld I, Bolton B (eds) (1988) The Hymenoptera. Oxford University Press. ISBN 0-19-858521-7

- Gibson GAP, Huber JT, Woolley JB (1997) Annotated Keys to the Genera of Nearctic Chalcidoidea (Hymenoptera). NRC Research Press. ISBN-13: 978-0660166698
- Gordon RD (1985) The Coccinellidae (Coleoptera) of America North of Mexico. *J N Y Entomol Soc* 93(1):i–912
- Goulet H, Huber JT (eds) (1993) Hymenoptera of the world: An identification guide to families. Research Branch Agriculture Canada Publication. ISBN 0-660-14933-8
- Hatt S, Döring TF (2024) The interplay of intercropping, wildflower strips and weeds in conservation biological control and productivity. *J Pest Sci*. <https://doi.org/10.1007/s10340-024-01801-1>
- Hernández-Trejo A, Estrada-Drouaillet B, Rodríguez-Herrera R, García-Giron JM, Patiño-Arellano SA, Osorio-Hernández E (2019) Importancia del control biológico de Plagas En maíz (*Zea Mays* L). *Revista Mexicana De Ciencias Agrícolas* 10(4):803–813. <https://doi.org/10.29312/remexa.v10i4.1665>
- James DG, Seymour L, Lauby G, Buckley K (2018) Identity and seasonal abundance of beneficial arthropods associated with big sagebrush (*Artemisia tridentata*) in central Washington state. USA. *Insects* 9(3):76. <https://doi.org/10.3390/insects9030076>
- Jocković J, Grahovac N, Milovac Ž, Jocković M, Jocić S, Jeromela AM, Cvejić S (2025) Exploring *Helianthus* species for resilience to drought during the critical reproductive stage. *Plants* 14(4):631. <https://doi.org/10.3390/plants14040631>
- Lenth R (2025) emmeans: Estimated Marginal Means, aka Least-Squares Means. R package version 1.11.1. <https://CRAN.R-project.org/package=emmeans>
- López V, Figueroa DI, García R, Villalobos F, Acosta-Duran C (2004) Parasitoides de insectos Plaga e Inocuidad alimentaria. México: Investigación Agropecuaria 1(1):57–61
- Lundin O, Boetzel FA, Ward KL, Williams NM (2023) Wildflower plantings have mixed effects on insect herbivores and their natural enemies. *Agric Ecosyst Environ* 355:108587
- Montoya P, Toledo J (2020) Estrategias de Control Biológico. En Montoya P, Toledo J, Hernández E (eds.) Moscas de la Fruta: Fundamentos y Procedimientos para su Manejo, pp 259–276. Ciudad de México: S y G Editores. ISBN 9786077552338
- New TR (2001) Introduction to the systematic and distribution of Coniopterygidae, hemerobiidae and Chrysopidae used in pest management. In: McEwen P, New TP, Whittington AE (eds) Lacewings in the crop environment. Cambridge University Press, Cambridge, U.K, pp 6–28. <https://doi.org/10.1017/CBO9780511666117>
- Norris RF, Kogan M (2000) Interactions between weeds, arthropod pests, and their natural enemies in managed ecosystems. *Weed Sci* 48(1):94–158. [https://doi.org/10.1614/0043-1745\(2000\)048](https://doi.org/10.1614/0043-1745(2000)048)
- Oliveira MC, Jhala AJ, Bernards ML, Proctor CA, Stepanovic S, Werle R (2022) Palmer amaranth (*Amaranthus palmeri*) adaptation to US Midwest agroecosystems. *Front Agron*. <https://doi.org/10.3389/fagro.2022.887629>
- Øyvind H, Harper D, Ryan P (2020) PAST: Paleontological statistics software package for teaching and data analysis. (4.17) [Software]. <https://www.nhm.uio.no/english/research/resources/past/>
- Salas-Araiza MD, Guzman-Mendoza R, Huerta-Arredondo IA, Leyte-Manrique A (2023) Weeds as reservoirs of beneficial insects to control pests in crops. *Southwest Entomol* 48(1):57–67. <https://doi.org/10.3958/059.048.0105>
- Straser RK, Daane KM, Stahl JM, Wilson H (2024) Floral resources enhance fitness of the parasitoid *Hadronotus pennsylvanicus* (Hymenoptera: Scelionidae) but not biological control of its host *Leptoglossus zonatus* (Heteroptera: Coreidae). *Environ Entomol* 53(2):213–222. <https://doi.org/10.1093/ee/nvae002>
- Wan N, Zheng X, Fu L, Kiær LP, Zhang Z, Chaplin-Kramer R, Dainese M, Tan J, Qiu S, Hu Y, Tian W, Nie M, Ju R, Deng J, Jiang J, Cai Y, Li B (2020) Global synthesis of effects of plant species diversity on trophic groups and interactions. *Nat Plants* 6(5):503–510. <https://doi.org/10.1038/s41477-020-0654-y>
- Wharton AR, Marsh PM, Sharkey MJ (1998) Manual Para Los géneros de La Familia Braconidae (Hymenoptera) Del Nuevo Mundo. The International Society of Hymenopterists
- Wibowo D, Rahardjo BT, Karindah S, Muhammad FN (2023) The diversity and abundance of weeds in sugarcane (*Saccharum officinarum*) plantations and its relationships with hymenoptera parasitoids diversity. *Biodiversitas J Biol Divers* 24(4). <https://doi.org/10.13057/biodiv/d240448>

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