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Sustainable Conservation in Maize Fields: Analysing the Impact of Cosmos caudatus Refugia on Natural Enemy Diversity

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ABSTRACT

Maize (Zea mays L.) cultivation is frequently affected by pest infestations that can reduce crop productivity. The use of refugia plants may support arthropods that provide ecological services in agricultural ecosystems. This study investigated the association between king's salad (Cosmos caudatus) refugia and the diversity and abundance of arthropods in maize fields. The study was conducted at the Field Laboratory of the Faculty of Agriculture, Halu Oleo University, Indonesia, from November 2025 to March 2026. A randomized block design with two treatments maize without refugia (R0) and maize with C. caudatus refugia (R1) and three replications was used. Arthropods were observed weekly from 1 to 6 weeks after planting using direct observation, sweep nets, and pitfall traps. Data were analyzed using analysis of variance (ANOVA) and t-tests. The results indicated higher arthropod abundance and Shannon–Wiener diversity index (H') values in R1 than in R0. The recorded arthropods represented four orders—Araneae, Coleoptera, Orthoptera, and Hymenoptera—and included predatory taxa and pollinators. Carabidae was reported as the most abundant family. The final total abundance and statistical significance should be reported only after the counts have been reconciled across the results tables and the analyses have been verified. Overall, the findings suggest that C. caudatus refugia may be associated with differences in arthropod community abundance and diversity in maize fields.

Keywords:, *Carabidae, Insect Diversity, Predator, Pitfall Trap, Sweep Net*

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INTRODUCTION

Maize (*Zea mays L.*) is a vital global food and feed commodity supporting food security. High in carbohydrates, it serves as a primary energy source in livestock feed and grows well across diverse environmental conditions (Nasution et al., 2024). However, maintaining stable maize production requires effective crop management strategies that address various biotic and abiotic constraints, particularly pest infestations that can reduce crop growth, productivity, and yield quality. Sustainable maize cultivation therefore requires pest management approaches that balance agricultural productivity with environmental protection.

However, maize cultivation is often threatened by pest infestations that damage leaves, stems, and ears, leading to suboptimal yields. To quickly suppress pest populations, farmers still predominantly rely on chemical pesticides as a practical solution (Adha & Supriyono, 2022). Although chemical pesticides can provide rapid pest suppression, excessive or inappropriate application may negatively affect beneficial insects, disrupt ecological balance, and increase dependence on synthetic pest control inputs. Consequently, environmentally friendly pest management strategies that conserve natural enemies are increasingly important for supporting sustainable maize production.

In Southeast Sulawesi, dry-shelled maize production has fluctuated drastically due to shifting harvest areas, climate changes, and pest attacks. BPS data shows production dropped from 130.4 thousand tons in 2023 to 79,444 tons in 2024, followed by shifting harvest areas between 9,000–18,000 ha in 2025. These fluctuations highlight the importance of strengthening maize cultivation practices, including ecological pest management strategies that support crop productivity while reducing unnecessary dependence on chemical pesticides. Although production changes can result from several interacting factors, pest management remains an important component of efforts to improve the sustainability of maize agroecosystems.

To address low productivity caused by limited pest management knowledge, Integrated Pest Management (IPM) utilizing refugia plants as ecological engineering is crucial. This method promotes natural, sustainable, and eco-friendly pest control to improve long-term crop yields in Southeast Sulawesi (Fithah et al., 2025). Refugia plants represent an important component of ecological engineering because they provide additional floral resources and suitable habitats that support the survival, reproduction, and activity of natural enemies in agricultural landscapes. Integrating flowering plants into maize fields may enhance biological control and reduce the ecological disadvantages associated with intensive pesticide use. However, the effectiveness of refugia may vary depending on plant species, flowering characteristics, habitat conditions, and the composition of natural enemy communities. Therefore, evaluating suitable

refugia species under local cultivation conditions is necessary to support the effective implementation of IPM.

Refugia plants serve as microhabitats providing alternative food sources like nectar and pollen, as well as shelter for natural enemies during extreme weather or pesticide exposure (Mustarin et al., 2023). Brightly colored flowering plants such as cosmos, sunflowers, and zinnia reduce reliance on synthetic pesticides by naturally boosting natural enemy populations. Previous studies have highlighted the potential of flowering refugia to improve habitat suitability for natural enemies and strengthen biological control in agricultural systems. In maize agroecosystems, the availability of floral resources and alternative habitats may influence the abundance and diversity of predators and parasitoids associated with maize crops. Nevertheless, the effectiveness of individual refugia species cannot be assumed to be identical across cropping systems because plant characteristics and local environmental conditions may influence the responses of natural enemy communities.

Since natural enemies play a significant ecological role in suppressing major maize pests without chemical costs (Nearti et al., 2022; Pu'u & Syatrawati, 2022), further research is needed to determine how specific refugia plants influence natural enemy communities in maize agroecosystems. In particular, the use of king's salad (Cosmos caudatus) as a refugia plant requires further evaluation in the context of maize cultivation in Southeast Sulawesi. The research gap addressed in this study is the need for a direct comparison of natural enemy diversity and populations between maize fields cultivated with and without C. caudatus refugia under local agroecological conditions. Although previous studies have discussed the ecological benefits of refugia plants, the effects of particular species should be assessed within their specific cropping environments to establish their potential contribution to biological control.

The novelty of this study lies in its specific evaluation of C. caudatus refugia in maize agroecosystems in Southeast Sulawesi, focusing on differences in natural enemy diversity and populations between fields with and without refugia. This comparison provides context-specific evidence regarding the potential role of C. caudatus in supporting natural enemy communities and informing locally appropriate IPM practices.

Based on this research gap, this study aims to evaluate the effect of king's salad (Cosmos caudatus) refugia on natural enemy diversity in maize crops. Specifically, the study seeks to (1) identify the diversity of natural enemies associated with maize fields cultivated with and without C. caudatus refugia and (2) compare natural enemy populations between the two cultivation conditions. The findings are expected to provide scientific evidence supporting the use of refugia plants as an ecological engineering strategy for sustainable maize pest management in Southeast Sulawesi.

METHODS

2.1 Research Location and Materials

This research was conducted at Field Laboratory Land 1 of the Faculty of Agriculture and the Plant Protection Laboratory, Halu Oleo University. The study was carried out over five months, from November 2025 to March 2026. The materials used in this research included local Muna maize seeds, *Cosmos caudatus* refugia seeds, cow manure, detergent powder, and label papers. The equipment utilized in this study consisted of measuring tapes, stakes, hoes, machetes, sweep nets, insect collection bottles, cameras, and stationery. The field laboratory was used for crop cultivation and natural enemy sampling, while the Plant Protection Laboratory was used for morphological examination and identification of collected specimens.

2.2 Experimental Design and Plot Arrangement

This study employed a Randomized Block Design (RBD) consisting of two treatments: maize without refugia (R_0) and maize with refugia (R_1). The experimental design included three blocks, with each treatment represented by eight plots per block. Based on this interpretation of the original plot allocation, the experiment comprised 48 plots in total, consisting of 24 plots for R_0 and 24 plots for R_1. Treatment allocation within each block was randomized to minimize the influence of spatial variation in field conditions. Each individual plot consisted of nine maize plants, resulting in 432 maize plants across the 48 plots, excluding reserve seedlings used for replanting.

The individual plot was defined as the experimental unit, provided that each plot received its assigned treatment independently. The eight plots per treatment within each block were considered subsamples or plot-level replicates according to the actual randomization procedure. The treatment allocation and independence of plots must be confirmed against the original field layout before the design is finalized.

2.3 Land Preparation and Crop Establishment

Land preparation began by clearing weeds and tilling the soil using hoes. The experimental area was divided into raised beds measuring 1.5 m × 1 m, with a height of 50 cm and a distance of 50 cm between beds. Meanwhile, *C. caudatus* seeds were soaked in water for three hours, germinated in trays containing well-decomposed cow manure, and transferred to polybags at three weeks after sowing (WAS). These seedlings were transplanted along the boundaries of the plots as a living barrier when they were approximately two months old, exactly one day before maize planting.

According to the original field procedure, the refugia plants were established before maize planting and were intended to provide floral resources and habitat for beneficial organisms. However, their actual

flowering stage at transplantation and during each sampling period should be documented to establish whether nectar and pollen were available throughout the observation period. The one-day interval between refugia establishment and maize planting should also be reported accurately because the refugia plants were already approximately two months old at transplantation.

For the main crop, viable local Muna maize seeds selected via a 12-hour water-soaking test were sown at a spacing of 75 cm × 25 cm, with two seeds per planting hole across nine holes per plot. Replanting was conducted as necessary using reserve seedlings to maintain uniformity. Crop maintenance involved routine watering twice daily in the absence of rain, biweekly manual weeding, and two fertilization applications using cow manure bokashi as a basal dressing and 50 g of NPK fertilizer during crop growth. Crucially, no chemical pesticides were applied throughout the study so that natural enemy communities could colonize and develop under field conditions without direct pesticide exposure. This management practice was applied consistently across both treatments to minimize differences in crop management other than the presence or absence of refugia.

2.4 Sampling Procedures and Organism Identification

Natural enemies were captured using sweep nets swung in a figure-eight pattern over the crop canopy for flying insects and pitfall traps containing soapy water for ground-dwelling organisms. Pitfall traps were installed with their openings flush with the soil surface to capture organisms moving across the ground. The detergent solution served as a trapping medium. The number of traps per plot, trap dimensions, detergent concentration, trap exposure duration, and sweep-net sampling effort were not specified in the original procedure and should be added from the actual field records. These details are necessary to ensure sampling consistency and reproducibility.

Observations were conducted weekly on all plots in the morning from one to six weeks after planting (WAP). The six observation periods were treated as repeated measurements of the same experimental plots rather than as six independent replications. At each observation, specimens captured using the two collection methods were recorded separately before the data were combined for analysis, where appropriate. The observation date, plot identification, treatment, sampling method, and number of individuals collected were recorded for each sampling event.

Collected specimens were identified morphologically, either visually for larger insects or using a microscope for smaller individuals, to determine their taxonomic groups and ecological roles. Identification was performed at the lowest taxonomic level reliably supported by the available morphological characteristics. Specimens that could not be identified confidently to species level were recorded at the appropriate genus, family, or order level rather than assigned an unsupported species

name. Identification should be verified using appropriate taxonomic keys or relevant entomological references, with voucher specimens retained where possible.

Ecological roles were assigned separately from taxonomic identification. Organisms were classified as predators, parasitoids, pollinators, or other functional groups only when supported by reliable taxonomic or ecological evidence. For example, *Apis dorsata* should be classified as a pollinator rather than a predator. Crickets should not automatically be classified as predators because their feeding habits vary among taxa; their functional classification must be supported by species-specific or family-level ecological evidence. Organisms whose roles could not be established reliably were recorded as unidentified or other functional groups rather than assumed to be biological control agents.

The total population abundance of each identified taxon was counted manually. Abundance was expressed as the number of individuals recorded per plot and observation period, with sampling effort standardized across treatments. Because sweep nets and pitfall traps sample different ecological components, their results were interpreted in relation to their respective sampling methods. The combined abundance data were used to describe the natural enemy community only after the sampling records and taxonomic classifications had been checked for consistency.

Shannon–Wiener Diversity Index

Natural enemy diversity was quantified using the Shannon–Wiener diversity index (H′), calculated as follows:

$$H' = -\sum_{i=1}^{s} (p_i \ln p_i)$$

Keterangan:

- H'= Shannon-Wiener diversity index
- s= Number of natural enemy species
- p_i= Proportion of individuals in the \(i\)-th species relative to the total individuals of all species, calculated as $p_i = \frac{n_i}{N}$
- n_i= Number of individuals in the i-th species
- N= Total number of individuals across all species

The index was calculated from the taxon-level abundance data for each plot and observation period, provided that sufficient identification and sampling records were available. Where diversity was calculated at the plot level, the resulting H′ values were used as the response variable in the statistical analysis. Pooled diversity indices could additionally be used to describe the overall community for each

treatment, but they should not be treated as independent plot-level observations. When no individuals were recorded during a sampling event, the Shannon–Wiener index was considered undefined for that event rather than assigned an arbitrary value.

The diversity values were interpreted using the following criteria:

$H' < 1{,}0 \rightarrow$ Low diversity

$1{,}0 \leq H' \leq 3{,}0 \rightarrow$ Moderate diversity

$H' > 3{,}0 \rightarrow$ High diversity

These thresholds were used as descriptive categories, and their interpretation was considered in relation to the taxonomic resolution, sampling effort, and ecological context of the study.

Statistical Analysis

The data obtained from this experiment were analyzed to determine differences in natural enemy abundance and diversity between maize plots with and without *C. caudatus* refugia. Because observations were conducted weekly on the same plots over six weeks, the measurements were not treated as independent observations. Treatment was considered a fixed effect, block was included to account for spatial variation, and observation week was incorporated as a repeated-measures factor. The treatment-by-week interaction was considered to assess whether treatment differences changed over the observation period.

For approximately continuous response variables, including plot-level Shannon–Wiener diversity indices, a repeated-measures linear mixed-effects model or an equivalent repeated-measures analysis was considered appropriate, provided that its assumptions were satisfied. The experimental plot, rather than each weekly observation, was treated as the experimental unit. Block was included as a random effect where supported by the design and model structure. The within-plot correlation among weekly observations was accounted for in the repeated-measures structure.

For natural enemy abundance data, the suitability of a count-data model was evaluated because counts may be skewed, contain many zeros, or exhibit variance greater than the mean. Generalized linear mixed-effects models with Poisson or negative binomial distributions could be used, depending on the observed distribution and dispersion of the data. If sampling effort differed among observations, an appropriate effort adjustment would also be required.

Before applying a parametric model, residual distributions and variance assumptions were evaluated using appropriate diagnostic procedures. Normality was assessed from model residuals rather than assumed solely from the raw observations, and homogeneity of variance and the adequacy of the repeated-measures covariance structure were also examined. Where assumptions were not adequately met, an appropriate alternative model or robust analytical procedure was considered.

Because the study involved only two treatments, the primary statistical comparison was the estimated contrast between R_0 and R_1. A separate t-test following ANOVA was not automatically required; any additional pairwise comparison would be justified only if the analytical model and research question required it. Statistical significance was evaluated at a 5% significance level ($\alpha = 0.05$), with effect estimates and confidence intervals reported where available. The final statistical procedure was selected according to the actual experimental layout, response-variable distributions, and repeated-measures structure.

RESULTS AND DISCUSSION

RESULTS

3.1 Effect of *Cosmos caudatus* Refugia on Natural Enemy Communities in Maize Crops

3.1.1 Temporal Variation in Natural Enemy Abundance, Taxonomic Richness, and Diversity

Table 1 presents the observed variation in taxonomic identification, richness, abundance, and Shannon–Wiener diversity of natural enemies in maize crops with (R_1) and without (R_0) *Cosmos caudatus* refugia during six weeks after planting (WAP).

Table 1. Observed Natural Enemy Community Characteristics during Six Weeks after Planting

Observed variable	Treatment	1 WAP	2 WAP	3 WAP	4 WAP	5 WAP	6 WAP
Number of orders	R_0	3	3	4	3	3	3
	R_1	5	5	6	5	5	4
Number of reported species	R_0	3	3	3	3	3	3
	R_1	5	5	5	5	6	4
Mean abundance (individuals per replicate)	R_0	3.67	1.67	3.67	2.00	1.67	2.33
	R_1	6.67	7.00	7.00	5.33	7.00	7.67
Shannon–Wiener diversity index (H′)	R_0	1.07	1.05	1.34	1.01	0.95	1.08
	R_1	1.54	1.59	1.74	1.57	1.58	1.33

Notes: R_0 = maize without refugia; R_1 = maize with *C. caudatus* refugia. WAP = weeks after planting. The reported species counts and diversity indices should be verified against the original taxon-by-plot dataset before publication. The R_0 abundance at 5 WAP is shown as 1.67 to agree with Tables 4 and 5.

As shown in Table 1, the number of identified orders varied between three and four in R_0 and four and six in R_1. The R_1 treatment generally contained more identified orders than R_0, suggesting a broader

representation of taxonomic groups in plots with refugia. However, order richness describes the number of higher taxonomic groups recorded and should not be interpreted as equivalent to species richness. The reported number of species also varied over time, although the consistency of these counts requires verification against the species-level identification records.

Natural enemy abundance differed between treatments throughout the observation period. The mean abundance in R_0 ranged from 1.67 to 3.67 individuals per replicate, whereas R_1 ranged from 5.33 to 7.67 individuals per replicate. These descriptive results indicate that plots with refugia consistently supported higher recorded natural enemy abundance during the six observation weeks. Nevertheless, statistical significance must be established using an analysis that accounts for the actual experimental replication and repeated observations.

The Shannon–Wiener diversity index ranged from 0.95 to 1.34 in R_0 and from 1.33 to 1.74 in R_1. The higher H′ values in R_1 indicate greater diversity according to this index, which reflects both taxon richness and the relative distribution of individuals among taxa. Abundance, richness, and diversity are distinct ecological measures: a larger number of individuals does not necessarily produce a higher H′ value if those individuals are concentrated in only a few taxa. Furthermore, the observed differences alone do not establish greater ecosystem stability or more effective pest suppression.

3.1.2 Identification and Abundance of Natural Enemy Taxa

Natural enemy specimens were identified using morphological characteristics and supporting taxonomic references. The reported taxonomic groups and their accumulated counts are presented in Table 2.

Table 2. Reported Taxonomic Composition and Accumulated Abundance of Arthropods in Maize Plots

No	Order	Family	Amount		Observation week	Image
			R0	R1		
1.	Araneae	Sparassidae	3	8	1,3,4,5	
2.	Araneae	Lycosidae	6	5	1,2,3,6	

3.	Araneae	Agelenidae	3	5	1,2,6	
4	Orthoptera	Gryllidae	9	20	1-5	
5.	Coleoptera	Carabidae	15	29	1-6	
6.	Coleoptera	Coccinellidae	5	24	1-6	
7.	Hymenoptera	Apidae	2	21	1,2,3,6	
8.	Hymenoptera	Crabronidae	3	10	3-5	
9.	Araneae	Thomisidae		1	5	

Notes: R_0 = maize without refugia; R_1 = maize with *C. caudatus* refugia. Counts are transcribed from the supplied table and have not been independently verified against the original field records. The observation-week entries should also be checked against the raw sampling sheets.

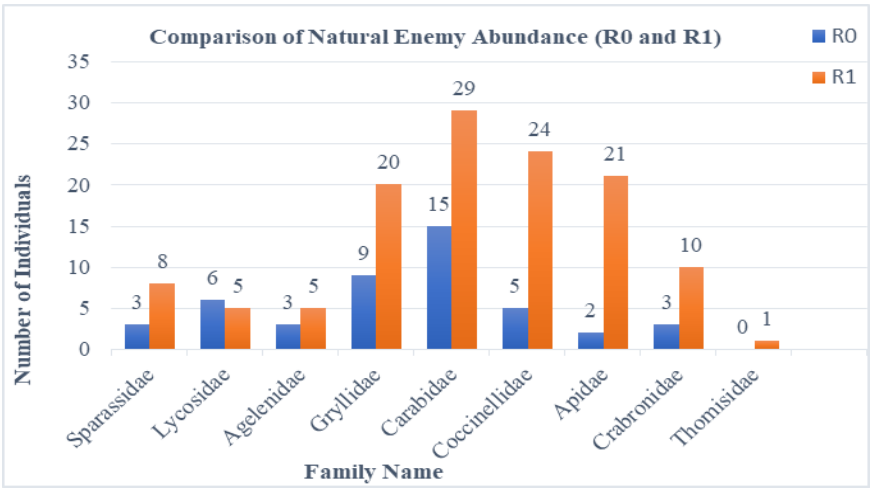
Based on Table 2, the identified arthropods represented four orders: Araneae, Orthoptera, Coleoptera, and Hymenoptera. The listed families indicate that the community included spiders, beetles, crickets, bees, and wasps. However, the taxonomic composition must be interpreted alongside the ecological role of each group because not every arthropod recorded in the crop is necessarily a natural enemy of maize pests.

Carabidae had the largest reported accumulated count in both treatments, with 15 individuals in R_0 and 29 in R_1. Coccinellidae also showed a higher reported count in R_1 than in R_0, with 24 and 5 individuals, respectively. These findings indicate that the two beetle families contributed substantially to the recorded arthropod abundance in the refugia treatment. Nevertheless, family-level abundance alone does not establish the extent of pest suppression; evidence about prey availability, feeding behavior, and actual predation would be needed to quantify biological control effectiveness.

The accumulated counts in Table 2 do not fully agree with the treatment totals reported elsewhere in the manuscript. The listed R_1 counts sum to 123 individuals, whereas the weekly totals in Table 5 sum to 122. The R_0 counts sum to 46 before accounting for the missing Thomisidae value, whereas the weekly totals in Table 5 sum to 45. These discrepancies must be resolved using the original specimen records before the final totals are reported.

3.2 Comparison of Natural Enemy Abundance

The comparison of accumulated natural enemy abundance between treatments is presented in Graph 1.



Graph 1. Accumulated Abundance of Identified Arthropod Taxa in Maize Plots with and without *C. caudatus* Refugia

Graph 1 should use the verified counts from Table 2, with the horizontal axis showing taxonomic families and the vertical axis showing the number of individuals. The legend should distinguish R_0 from R_1.

The reported family-level counts generally show higher abundance in R_1 for several groups, including Carabidae, Coccinellidae, Apidae, and Crabronidae. This pattern is consistent with the possibility that refugia-associated habitat and floral resources supported greater arthropod presence. However, the effect should not be attributed solely to nectar availability because some recorded groups may benefit from shelter, alternative prey, or other habitat characteristics. Moreover, Apidae are pollinators rather than predators, and their presence should be discussed as a contribution to pollination and broader agroecosystem functions rather than direct pest suppression.

The term "significantly higher" should be used only after the treatment comparison has been confirmed by an appropriate statistical test. A graph showing different counts establishes a descriptive difference, not statistical significance by itself.

3.3 Taxonomic Identity and Ecological Roles

The study reported nine taxonomic entries belonging to four orders. Because some entries were identified only to family or genus level, the number of confirmed species cannot be established from the current table without additional identification evidence. Table 3 therefore distinguishes the reported common names and taxonomic identities from their ecological roles.

Table 3. Reported Arthropod Taxa and Their Ecological Roles

No.	Common name	Reported scientific name or taxon	Order	Family	Ecological role to report
1	Ground beetle	Carabidae	Coleoptera	Carabidae	Predatory for taxa with confirmed predatory feeding habits
2	Ladybird beetle	*Oenopia conglobate*	Coleoptera	Coccinellidae	Predatory, subject to confirmation of identification
3	Cricket	Gryllidae	Orthoptera	Gryllidae	Verify feeding ecology; do not automatically classify as a predator
4	Huntsman spider	*Heteropoda venatoria*	Araneae	Sparassidae	Predator
5	Wolf spider	*Lycosa* sp.	Araneae	Lycosidae	Predator
6	Sheetweb spider	*Tegenaria domestica*	Araneae	Agelenidae	Predator; verify species identification

7	Crab spider	*Misumena* sp.	Araneae	Thomisidae	Predator
8	Wasp	*Pison* spp.	Hymenoptera	Crabronidae	Predatory or provisioning wasp; verify identification and behavior
9	Giant honey bee	*Apis dorsata*	Hymenoptera	Apidae	Pollinator, not predator

Note: Scientific names and ecological classifications should be verified against taxonomic references and the specimens collected. Family-level identification must not be presented as confirmed species-level identification.

The reported community included several spider families, including Sparassidae, Lycosidae, Agelenidae, and Thomisidae. Spiders are generally predatory arthropods and may contribute to biological control by consuming insect prey. However, the magnitude of their contribution to maize pest suppression cannot be inferred from their abundance alone. Their prey composition and interactions with target pest species were not quantified in the information provided.

Other recorded groups included Carabidae and Coccinellidae, which contain many predatory beetles, and Crabronidae, which includes wasps with diverse prey-provisioning behaviors. The role of Gryllidae requires particular care because crickets may be omnivorous, herbivorous, scavenging, or predatory depending on the taxon and context. Their classification as natural enemies should therefore be retained only when supported by reliable ecological evidence. Similarly, *Apis dorsata* should be classified as a pollinator because it visits flowers for floral resources; its presence does not demonstrate direct predation on maize pests.

Correct ecological classification is essential for interpreting community composition. Combining predators, pollinators, and other arthropods into a single “natural enemy” category without qualification may overestimate the number of biological control agents and obscure the different ecological functions supported by refugia plants.

3.4 Comparison of Natural Enemy Abundance across Observation Weeks

Table 4 presents the reported mean abundance of arthropods in the two treatments during the six observation weeks.

Table 4. Mean Arthropod Abundance by Treatment and Observation Week

WAP	R_0 (individuals per replicate)	R_1 (individuals per replicate)	Descriptive difference ($R_1 - R_0$)	Reported t-value	Reported p-value
1	3.67	6.67	3.00	5.20	0.035

2	1.67	7.00	5.33	6.05	0.026
3	3.67	7.00	3.33	10.00	0.010
4	2.00	5.33	3.33	10.00	0.010
5	1.67	7.00	5.33	6.05	0.026
6	2.33	7.67	5.34	16.00	0.004

Notes: R_0 = maize without refugia; R_1 = maize with *C. caudatus* refugia; WAP = weeks after planting. The t-values and p-values are reproduced from the supplied manuscript and require recalculation or verification from the replicate-level data. The descriptive differences are calculated from the reported means.

Table 4 shows that the mean recorded abundance was higher in R_1 than in R_0 during all six observation weeks. The largest descriptive differences occurred at 6 WAP (5.34 individuals per replicate) and at 2 and 5 WAP (5.33 individuals per replicate). The smallest difference occurred at 1 WAP (3.00 individuals per replicate). These comparisons describe the observed pattern but do not independently establish statistical significance.

The original analysis reports significant differences in each week. However, the reported critical t-values imply a small number of degrees of freedom, and the relationship between the experimental layout, the reported t-statistics, and the p-values must be checked. If the same plots were observed repeatedly, weekly observations should not be treated as independent experimental replicates. The final analysis should account for block structure, plot-level replication, and within-plot correlation over time.

A repeated-measures mixed-effects model or a suitable generalized mixed-effects model should be selected according to the response variable and the actual design. The treatment effect and treatment-by-week interaction can then be evaluated without inflating the effective sample size. Until the original data have been reanalyzed, the statement that R_1 was significantly different from R_0 in every week should be considered provisional.

3.5 Shannon–Wiener Diversity Index

The Shannon–Wiener index describes diversity by combining the number of taxa and the relative abundance of each taxon. The reported values for each treatment and observation week are presented in Table 5.

Table 5. Reported Taxon Richness, Total Abundance, and Shannon–Wiener Diversity Index

WAP	Treatment	Reported number of species (S)	Total individuals (N)	H′	Diversity category
1	R_0	3	11	1.07	Moderate

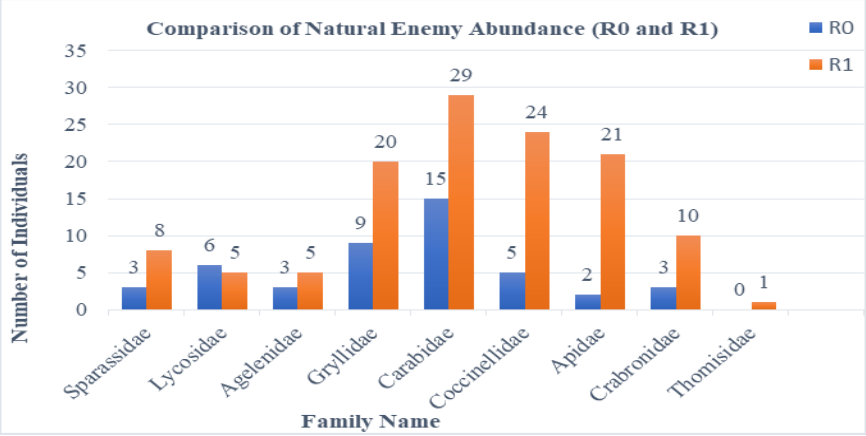
	R_1	5	20	1.54	Moderate
2	R_0	3	5	1.05	Moderate
	R_1	5	21	1.59	Moderate
3	R_0	Verify	11	1.34	Moderate
	R_1	Verify	21	1.74	Moderate
4	R_0	3	6	1.01	Moderate
	R_1	5	16	1.57	Moderate
5	R_0	3	5	0.95	Low
	R_1	Verify	21	1.58	Moderate
6	R_0	3	7	1.08	Moderate
	R_1	4	23	1.33	Moderate

Notes: R_0 = maize without refugia; R_1 = maize with *C. caudatus* refugia; WAP = weeks after planting. The number of species in weeks 3 and 5 requires verification because Table 1 reports different values. H′ values and total counts must be recalculated from the underlying taxon-level abundance data if discrepancies are confirmed.

The reported Shannon–Wiener index was higher in R_1 than in R_0 during all six observation weeks. The highest reported value was 1.74 in R_1 at 3 WAP, whereas the lowest was 0.95 in R_0 at 5 WAP. Using the stated classification criteria, the R_1 values fell within the moderate-diversity category throughout the observation period, while R_0 fell into the low-diversity category at 5 WAP and the moderate category during the other weeks.

The diversity index should be interpreted separately from abundance and richness. Abundance refers to the number of individuals recorded, richness refers to the number of distinct taxa, and H′ reflects both richness and the relative distribution of individuals among taxa. Therefore, a higher H′ does not automatically mean that more individuals were recorded, that more species were present, or that the ecosystem was more stable. The R_1 pattern is consistent with a potential association between refugia planting and greater natural enemy diversity. Nevertheless, the strength of this conclusion depends on confirming the taxonomic counts and recalculating H′ using the same taxonomic resolution and sampling effort across treatments. The reported H′ values alone do not demonstrate a statistically significant treatment effect unless plot-level diversity values are analyzed with an appropriate statistical model.

3.5 Comparison of Natural Enemy Diversity



Graph 2. ***Shannon–Wiener Diversity Index (H') of Arthropods in Maize Plots with and without C. caudatus Refugia during Six Weeks after Planting***

Graph 2 compares the reported H′ values for R_0 and R_1 from 1 to 6 WAP. The graph should display the six weekly H′ values for each treatment, use consistent decimal notation, identify the index as H′, and include a clear legend. If the values represent means across replicate plots, variability measures such as standard deviations or confidence intervals should be included where available.

The reported values show that R_1 had a higher H′ than R_0 at each observation. This descriptive pattern suggests that the refugia treatment may have supported a more diverse distribution of recorded arthropod taxa. However, it should not be described as a statistically significant increase until the replicate-level diversity data have been analyzed. Nor should higher H′ be interpreted as proof of greater ecosystem stability or improved pest control without additional evidence.

Overall, the results suggest that maize plots with *C. caudatus* refugia had higher recorded arthropod abundance and higher reported Shannon–Wiener diversity than plots without refugia. These findings support further investigation of refugia as a habitat-management strategy in maize agroecosystems. The final conclusions must, however, be based on verified taxonomic records, consistent totals, recalculated diversity indices, and statistical tests that reflect the actual experimental design.

DISCUSSION

4.1 Natural Enemy Composition and the Ecological Role of Spiders

Based on field observations in the maize field, several spider families from the order Araneae were identified, namely Lycosidae, Agelenidae, Sparassidae, Thomisidae, and Oxyopidae. Morphologically, a

spider's body is divided into two main regions: the cephalothorax and the abdomen, equipped with eight legs and no antennae. Spiders exhibit variations in size and coloration, generally ranging from brown to grayish, which serves as camouflage within the field environment. Behaviorally and structurally, the families display distinct traits: Lycosidae are active hunters that do not spin prey-capture webs, whereas Agelenidae construct funnel-shaped webs. Additionally, the Thomisidae family possesses enlarged front legs resembling those of a crab, while the Oxyopidae family is characterized by spiny legs and well-developed vision (Septa et al., 2025). These morphological characteristics are useful for preliminary identification and illustrate the functional diversity of spiders in agricultural habitats. However, the identification of Oxyopidae should be reconciled with the taxonomic records presented in the results because this family does not appear in the current version of Table 2, which instead lists Thomisidae and four other spider families.

Spider populations were observed almost every week, from week 1 to week 6 of the observation period, in both the treated plot with refugia (R_1) and the control plot without refugia (R_0). Ecologically, spiders act as generalist predators that prey on various insects, including caterpillars and other small arthropods. The presence of these spiders demonstrates their potential role in maintaining ecological balance and helping to suppress pest populations naturally (Dewi et al., 2019). Different spider families may contribute to biological control through different foraging strategies. Active hunters, such as wolf spiders, search for prey on the soil surface and vegetation, whereas web-building spiders capture susceptible insects that encounter their webs. Crab spiders can ambush visiting insects on flowers and surrounding vegetation. These complementary hunting strategies may increase the range of prey encountered within the crop habitat.

The ecological contribution of spiders may also be influenced by refugia plants through habitat modification. Flowering vegetation can increase structural complexity, provide resting or hunting sites, and influence the availability of prey and other resources. These mechanisms offer a plausible explanation for the presence of spiders in maize plots containing refugia. Nevertheless, the present observations establish the occurrence of spiders rather than directly measuring their predation rates or the resulting reduction in maize pest populations. Consequently, the contribution of spiders to pest suppression should be interpreted as an ecological potential rather than a directly demonstrated outcome.

4.2 Ground Beetles and Ladybird Beetles as Potential Biological Control Agents

One of the ground-dwelling insect groups that plays an important role in agricultural ecosystems is the ground beetle. Ground beetles belong to the family Carabidae within the order Coleoptera (Safitri & Haryadi, 2023). These beetles possess hardened forewings, known as elytra, and many species have

elongated bodies, strong running legs, and well-developed mandibles used to capture prey. Their activity patterns vary among species, although many ground beetles forage on or near the soil surface.

Ground beetle populations were recorded throughout the observation period, with higher accumulated counts in the treated plots containing refugia. Ecologically, many Carabidae are predators that consume insect eggs, larvae, and other small arthropods, thereby potentially contributing to pest regulation in maize fields. The accumulated counts reported in Table 2 were 15 individuals in R_0 and 29 individuals in R_1. This difference is consistent with the possibility that the refugia treatment provided habitat conditions favorable to the occurrence of ground beetles. However, the family Carabidae also contains species with different feeding habits, and the predatory role of the recorded specimens should be interpreted according to the taxonomic resolution achieved in this study.

Refugia may influence ground beetles indirectly by modifying vegetation structure, providing shelter from environmental stress, and affecting the availability of prey or alternative food. These mechanisms may be particularly relevant for ground-active arthropods when vegetation management changes the microhabitat at the soil surface. However, because the study did not separately measure soil moisture, prey availability, or beetle movement, the relative contribution of these mechanisms remains uncertain.

The family Coccinellidae, commonly known as ladybird beetles, includes many species that act as predators of sap-feeding pests, including aphids and certain scale insects. Morphologically, these beetles often have a rounded, convex body with hardened forewings that protect the hindwings. Their conspicuous coloration may function as a warning signal to potential predators (Husaeri, 2025).

Ladybird beetles were recorded during several observation weeks using the sweep-net method. Ecologically, many coccinellids are important predators of small insects and can contribute to crop pest management. The reported counts of Coccinellidae were five individuals in R_0 and 24 individuals in R_1. This pattern suggests that more ladybird beetles were recorded in plots with refugia. The presence of flowering plants may support some beneficial arthropods by improving habitat conditions or attracting prey and other resources. Nevertheless, the availability of aphids and other prey was not quantified in the present study, so the mechanism responsible for the observed difference cannot be identified conclusively.

The findings are broadly consistent with the ecological rationale for conserving predatory beetles in agricultural systems. However, differences in the abundance of Carabidae and Coccinellidae should not be interpreted as direct evidence that maize pest populations declined. Demonstrating that outcome would require measurements of pest abundance, predation, or crop damage in addition to natural enemy counts.

4.3 Hymenoptera: Predatory Wasps and Pollinators

The order Hymenoptera includes insects with important ecological functions, including pollination and biological control. Bees contribute to pollination, whereas some wasps prey on other arthropods or provision their nests with captured prey (Ramadhan et al., 2022).

The presence of Hymenoptera, represented in this study by the families Apidae and Crabronidae, showed higher accumulated counts in the treated plots. Morphologically, many members of Apidae possess branched body hairs that facilitate pollen collection and transport, making them important pollinators. Members of Crabronidae include solitary wasps that capture and provision prey for their offspring. These two families should be distinguished by ecological function: Apidae are primarily relevant to pollination in this study, whereas Crabronidae may contribute to biological control depending on the prey and behavior of the identified taxa.

The observed flight activity around cosmos flowers and maize plants during the day suggests that the vegetation provided a habitat visited by these insects. Flowering refugia can provide nectar and pollen for bees and other flower-visiting insects, while some predatory wasps may benefit from floral resources, suitable nesting conditions, or access to prey. These mechanisms provide a plausible ecological explanation for the higher number of Hymenoptera recorded in R_1. However, the study did not measure visitation rates, pollination success, or crop yield attributable to pollinators. Therefore, the potential contribution of refugia to pollination services should be distinguished from demonstrated improvements in maize productivity.

The species-level identity and ecological behavior of the recorded Crabronidae should also be verified before assigning a specific prey type. The family includes wasps with different prey preferences, and it is not appropriate to conclude that all recorded individuals specifically suppress Lepidopteran larvae without direct identification or supporting evidence.

4.4 Gryllidae and the Interpretation of Functional Groups

The family Gryllidae (crickets) contributed 29 individuals according to the accumulated counts reported in Table 2, with 20 individuals in the treated plots (R_1) and nine in the control plots (R_0). Morphologically, crickets possess chewing mouthparts and enlarged hind legs adapted for jumping. Their activity during the first five observation weeks indicates that they were present in the maize plots during the early stages of crop growth.

However, the ecological role of Gryllidae requires careful interpretation. Crickets exhibit varied feeding habits, including herbivory, omnivory, scavenging, and, in some taxa, predation. Their presence and abundance therefore cannot automatically be interpreted as evidence of increased biological control.

The higher cricket count in R_1 may reflect differences in habitat structure, food availability, or other environmental conditions, but the present data do not establish which mechanism was responsible.

The concept of a "ground-level biological control community" may be useful for discussing ground-active predators such as Carabidae and Lycosidae, provided their ecological roles are supported by identification evidence. Gryllidae should be discussed separately unless predatory behavior has been confirmed. This distinction prevents the abundance of all arthropods from being equated with the abundance of effective natural enemies.

4.5 Ecological Mechanisms Linking Refugia to Arthropod Communities

The observed arthropod community included spiders from several families, beetles from Carabidae and Coccinellidae, crickets from Gryllidae, wasps from Crabronidae, and bees from Apidae. These groups perform different ecological functions, including predation, other forms of arthropod feeding, and pollination. Their presence illustrates the range of arthropod groups recorded in the maize agroecosystem, but it does not by itself demonstrate that the ecosystem was more stable or that a self-sustaining pest-control system had been established.

Several ecological mechanisms may explain why plots containing *Cosmos caudatus* refugia recorded higher arthropod abundance and higher reported Shannon–Wiener diversity. First, flowering refugia can provide nectar and pollen to flower-visiting insects and some beneficial arthropods. Second, additional vegetation may increase structural complexity and create resting, sheltering, or foraging sites. Third, changes in habitat conditions may influence the distribution of prey and alternative food resources, indirectly affecting predatory arthropods. Finally, the availability of these resources may influence whether arthropods remain in or move through the maize plots.

These mechanisms are consistent with the ecological-engineering rationale for refugia plants in integrated pest management. However, their individual contributions were not measured directly in the present experiment. The study did not separately quantify nectar availability, flower visitation, prey abundance, arthropod movement, or predation rates. Consequently, the observed treatment differences are consistent with a beneficial association between refugia and arthropod communities, but they do not establish the precise mechanism responsible for that association.

4.6 Differences in Natural Enemy Abundance between Treatments

The six-week observations indicated that the mean recorded abundance of arthropods was higher in the R_1 treatment than in the R_0 treatment at every observation time. At 1 WAP, the reported mean was 6.67 individuals per replicate in R_1 and 3.67 in R_0. At 2 and 5 WAP, the corresponding values were 7.00 and 1.67 individuals per replicate, respectively. At 6 WAP, the reported means were 7.67 in R_1 and 2.33 in R_0.

These descriptive differences indicate a consistent pattern of higher recorded arthropod abundance in maize plots containing refugia. The pattern is compatible with the hypothesis that refugia provide additional habitat resources that influence arthropod presence. However, the abundance figures should be interpreted only after confirming that the same sampling effort, taxonomic inclusion criteria, and experimental replication were applied consistently to both treatments.

The original analysis reports significant differences between R_0 and R_1 across the observation period**.** Nevertheless, the reported t-statistics and p-values require verification using the replicate-level dataset. Because the same plots were observed over six consecutive weeks, the weekly observations are repeated measurements rather than independent experimental replicates. A statistical model that accounts for treatment, block, observation week, and within-plot correlation is needed to determine whether the treatment effect is statistically supported. Until this reanalysis is completed, the observed differences should be described as descriptive rather than definitively significant.

The higher recorded abundance in R_1 may be associated with the presence of refugia plants, which can provide microhabitats and floral resources. In contrast, maize plots without refugia lack this additional vegetation component. Nevertheless, the lower counts in R_0 do not demonstrate that natural enemies were unable to survive or were not attracted to the control plots. Arthropod abundance can also be affected by weather, crop development, prey availability, dispersal, and sampling efficiency. The contribution of refugia should therefore be evaluated in relation to these potential influences rather than attributed to a single mechanism.

Taken together, the results provide preliminary evidence that the presence of *C. caudatus* refugia was associated with higher recorded arthropod abundance during the six-week observation period. Whether this pattern translates into more effective biological control remains a separate question because pest suppression and crop damage were not directly measured.

4.7 Natural Enemy Diversity and the Shannon–Wiener Index

The Shannon–Wiener diversity index (H′) was higher in R_1 than in R_0 throughout the six observation weeks according to the reported values. The R_1 values ranged from 1.33 to 1.74, whereas the R_0 values ranged from 0.95 to 1.34. Under the diversity categories used in this study, the R_1 values fell within the moderate category, while the R_0 value at 5 WAP fell into the low category (Ningrum et al., 2025).

The consistently higher reported H′ values suggest that the distribution of individuals among recorded taxa differed between treatments. Unlike total abundance, the Shannon–Wiener index incorporates both the number of taxa and their relative abundances. A treatment may therefore have a high number of individuals but a relatively low diversity index if most individuals belong to only one or a few

taxa. Conversely, a community with fewer individuals may exhibit a higher index if those individuals are distributed more evenly among taxa.

The highest reported H′ value in R_1 occurred at 3 WAP, reaching approximately 1.74. This value indicates moderate diversity according to the study's stated thresholds. However, the index cannot be explained by species richness or total abundance alone. Its interpretation requires the relative abundance of each taxon, and the reported richness and total-individual figures must be reconciled before the index is recalculated and confirmed.

The presence of refugia may influence diversity by changing resource availability and habitat structure, potentially allowing different arthropod groups to coexist. However, higher H′ does not automatically establish greater ecosystem stability, improved resilience, or more effective pest suppression. Those conclusions require additional evidence, such as repeated seasonal observations, measurements of pest populations, or direct assessment of ecological interactions.

The control plots generally showed lower reported diversity values, including the low value recorded at 5 WAP. This pattern suggests that the arthropod community in R_0 may have been less diverse during that observation period. Nevertheless, the difference should be interpreted in light of sampling effort, taxonomic resolution, and the consistency of the underlying abundance data. The H′ values should be recalculated from verified taxon-level counts before the treatment effect is stated conclusively.

Spiders were among the frequently recorded arthropods in the maize plots, consistent with the importance of Araneae as predators in many agricultural ecosystems (Putra & Utami, 2020). Their occurrence contributes to the taxonomic and functional composition of the recorded community, but the proportion of spiders within the overall assemblage should be calculated from verified counts before claiming that the community was dominated by this order.

4.8 Implications for Integrated Pest Management

The findings have potential implications for the use of refugia plants as an ecological-engineering component of integrated pest management. The higher recorded arthropod abundance and higher reported H′ values in R_1 suggest that planting *C. caudatus* alongside maize may help support a broader arthropod community under the conditions of this study. The results provide a basis for further testing of flowering refugia as a habitat-management strategy in maize production systems.

However, practical recommendations should distinguish three outcomes: arthropod abundance, taxonomic diversity, and biological control effectiveness. The first two were assessed in this study, although the underlying counts and diversity indices require verification. The third was not measured directly because pest populations, crop damage, and predation rates were not reported. Therefore, the

results support the potential ecological value of refugia but do not yet establish that *C. caudatus* reduced maize pest populations or increased maize yield.

Future research should validate the taxonomic identification of recorded arthropods, quantify pest abundance alongside natural enemies, measure the flowering period and floral resources of *C. caudatus*, and evaluate treatment effects across additional seasons or locations. Statistical analysis should also use the actual plot-level experimental units and account for repeated observations. These improvements would clarify whether the observed community differences are reproducible and whether they translate into measurable pest-management benefits.

CONCLUSION AND IMPLICATIONS

Based on the research findings regarding the effect of king's salad (Cosmos caudatus) as a refugia plant on the diversity of arthropods in maize (Zea mays L.) crops, it can be concluded that:

1. Maize plots with C. caudatus refugia exhibited higher reported Shannon–Wiener diversity index (H′) values than plots without refugia throughout the 1–6 weeks after planting (WAP) observation period. The reported H′ values ranged from 1.33 to 1.74 in the refugia treatment and from 0.95 to 1.34 in the control treatment. These findings suggest that the presence of C. caudatus refugia was associated with differences in the diversity of the recorded arthropod community. However, the statistical significance of this difference requires confirmation using verified plot-level data and an appropriate repeated-measures analysis.
2. The recorded arthropod abundance was consistently higher in maize plots with refugia than in plots without refugia across the six observation weeks. The accumulated counts reported in Table 2 were 123 individuals in the refugia treatment and 46 individuals in the control treatment, although these totals require reconciliation with the weekly records in Table 5 before being accepted as final values. The findings indicate a potential association between C. caudatus refugia and greater arthropod abundance under the conditions of this study. However, the results do not establish that refugia directly suppressed maize pests or increased maize yield because pest abundance, crop damage, and yield were not measured.

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