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Investigating the Biodiversity of Predatory Insects in Different Intercropping Patterns of Safflower (*Carthamus tinctorius* L.) and Chickpea (*Cicer arietinum* L.)

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ABSTRACT

Investigating predatory insect biodiversity in intercropping systems is essential for sustainable pest management. This study aimed to evaluate the effect of intercropping patterns of safflower and chickpea on the biodiversity of predatory insects. The experiment was conducted using an RCBD with 11 treatments and 3 replications at the research farm of the Kurdistan University, Iran. The experimental treatments included sole cropping of safflower and chickpea, replacement series with ratios of 4:4, 2:2, 1:1, 3:1, and 1:3, as well as additive series with 20% and 40% chickpeas, each in two configurations: (I) within the rows and (II) around the rows of safflower. To collect and estimate the abundance and diversity of insects in the different cropping patterns, insect nets and pitfall traps were employed. Among the collected samples, five important families of natural enemies of pests—Syrphidae, Carabidae, Coccinellidae, Staphylinidae, and Chrysopidae—were selected for analysis of their diversity and abundance. The highest number of chrysopidae, carabidae and coccinellidae was observed in the 1:1 intercropping pattern with averages of 41, 21.67 and 14.33 individuals, respectively. The highest number of individuals of the Staphylinidae family was observed in the 4:4 cropping pattern, with an average of 19.33, and the highest number of individuals of the Syrphidae family was observed in the pure safflower crop with an average of 9.33. In terms of biodiversity, based on both Shannon-Wiener and Simpson indices, among the different intercropping patterns, the 3:1 and 1:3 patterns (with averages of 0.747 and 0.744 according to the Shannon-Wiener index and 5.57 and 5.43 according to the Simpson index, respectively) showed superiority over other intercropping patterns. Overall, the results showed that safflower-chickpea intercropping is able to increase the biodiversity of natural predators in agricultural ecosystems. This can be considered as one of the practical and important strategies for biological pest control.

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1. Introduction

Safflower (*Carthamus tinctorius* L.) is a versatile plant belonging to the Asteraceae family, valued for its agricultural, industrial, and medicinal uses. Iran is recognized as one of the most resource-rich regions in the world regarding safflower genetic diversity. This plant exhibits the highest drought resistance among oilseed crops and can be cultivated during the dry season, making it a viable option for farming in light of the country's water management challenges. Nonetheless, issues such as pests and diseases contribute to limitations on safflower seed yields (Anjum *et al.*, 2024). To mitigate pest damage in safflower fields, chemical insecticides are typically employed; however, the safety of the resulting products concerning chemical residue and their effects on human health and the environment necessitates careful consideration of the production methods and inputs used. This highlights the need for and justifies changes in conventional agricultural practices (Zhou *et al.*, 2025). In sustainable agricultural systems, natural self-regulation processes such as pest control and nutrient cycling are facilitated by biodiversity. However, monoculture systems have disrupted these self-

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regulating features, resulting in an input-dependent system (Karuppiah *et al*., 2025). Intercropping is one of the sustainable agricultural practices that maintains and increases biodiversity (Ullah *et al*., 2025). One of the benefits of plant diversity through intercropping is pest control, achieved by increasing the population of natural enemies (Thompson *et al*., 2025). In fact, altering the spatial arrangement of host plants or increasing the abundance of non-host plants can effectively control herbivorous pests (Shao *et al*., 2025). Several studies have reported the positive effects of intercropping different plants on improving insect biodiversity. For example, in the intercropping of spring turnip rape (*Brassica rapa* L. ssp. oleifera) and faba bean (*Vicia faba* L.), the highest population of natural predators was observed in the intercropping, while the highest population of pests was found in the sole cropping (Järvinen *et al*., 2023). Additionally, in an investigation of intercropping Corn–Soybean, both the Shannon-Wiener diversity index and predator density were significantly higher than those observed in monoculture across all intercropping treatments (Wei *et al*., 2025). Intercropping plants from different genera with leguminous plants is one of the most common forms of intercropping. The significance of this system lies in nitrogen fixation by leguminous species; part of the nitrogen is utilized in the same season, while another portion is available for the next planting season (Kokkini *et al*., 2025). With this context in mind, the purpose of this experiment was to leverage the favorable conditions of intercropping for optimal safflower production while minimizing the use of chemical inputs to prevent their adverse effects on human health and the environment. Therefore, we evaluated the biodiversity characteristics of several important insect families that play a role in biological pest control in different patterns of replacement and additive intercropping of safflower and chickpea.

2. Materials and methods

2.1. Experimental site

This experiment was conducted at the research farm of Kurdistan University, located 45 kilometers east of Sanandaj city, at a geographical longitude of 47° 18' E, a geographical latitude of 35° 19' N, and an altitude of 1,866 meters above sea level. The physical and chemical characteristics of the soil at the test site are presented in Table 1, while the meteorological information for this location is shown in Fig. 1.

Table 1. Physical and chemical properties of site soil

Clay (%)	Sand (%)	Silt (%)	C (%)	N (%)	P (ppm)	K (ppm)	EC (DS m^{-1})	pH
42.8	12.3	44.9	1	0.11	13	406	0.4	7.72

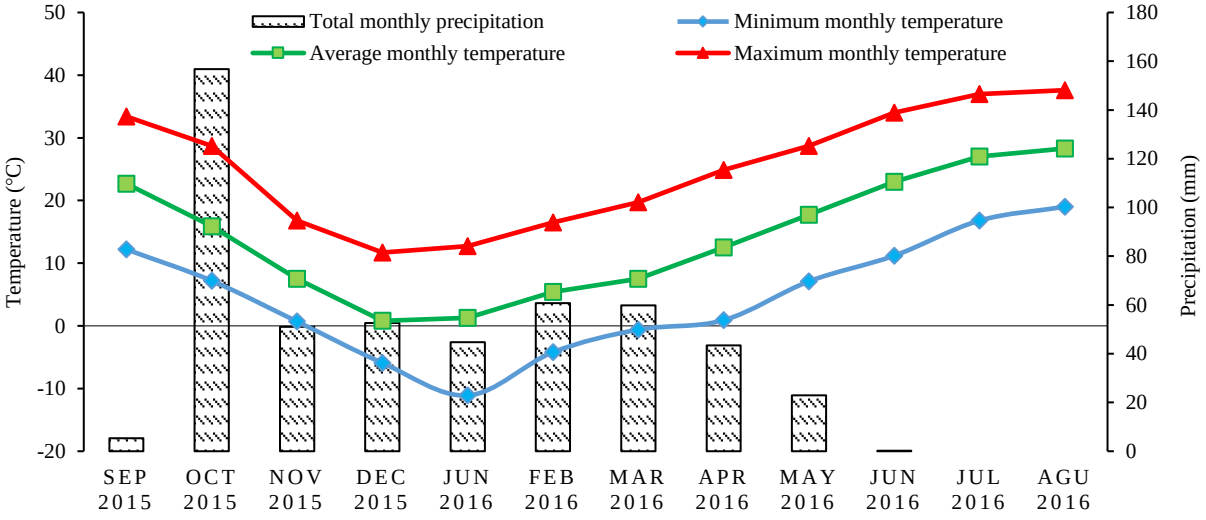


Figure 1. Meteorological information on the location of the experiment.

2.2. Experimental design description

The study was conducted using a randomized complete block design with 11 treatments and 3 replications. The experimental treatments consisted of various cultivation patterns, including sole cultivation of safflower and chickpea plants, as well as replacement intercropping in ratios of 4:4, 2:2, 1:1, 3:1, and 1:3. Additionally, there were treatments with 20%

and 40% additive intercropping of chickpeas, utilizing four planting arrangements: 20%I (20% chickpeas between safflower rows), 20%II (20% chickpeas around safflower rows), 40%I (40% chickpeas between safflower rows), and 40%II (40% chickpeas around safflower rows).

The row spacing and plant spacing within rows were set at 35 cm and 10 cm, respectively, with safflower and chickpea seeds sown simultaneously. Safflower seeds from the Sina variety and chickpea seeds from the Pirouz variety (Desi type) were used in this study, both of which are dry varieties cultivated in spring. Each block had a spacing of 4 meters between plots and 5 meters between blocks to ensure that adjacent plots did not interfere with the study of insect populations (Rezaei Chiyaneh *et al*., 2014). Weeding during the growing season was performed manually as needed. Based on soil test results and considering the fertilizer needs of safflower plants, no fertilizers or insecticides were used during land preparation or plant growth to maintain low-fertilization conditions and avoid disrupting insect abundance and diversity. Thinning was conducted to achieve optimal plant density at the 4-6 leaf stage (Khorramdel *et al*., 2016). In sole cropping and replacement intercropping patterns, the target density was 28.5 plants per square meter. In the additive intercropping pattern with a 20% increase, the target density was 34 plants per square meter, and in the additive intercropping pattern with a 40% increase, it was 40 plants per square meter.

2.3. Assessing the abundance and diversity of insect populations

To assess insect population abundance and diversity across different safflower and chickpea intercropping patterns, sampling occurred from canopy formation until harvest. This involved using a standard insect net to sample winged insects above the soil surface and placing pitfall traps in the soil to capture wingless, mobile, and shade-loving insects (Triplehorn *et al*., 2005). The pitfall traps measured 20 cm in depth and 15 cm in diameter (Duelli *et al*., 1999) and were covered with metal mesh to prevent the entry of small rodents and amphibians. Plastic containers were used as a shade to prevent rainwater from entering the traps. Three traps were installed in each plot, numbered for easy management. One-third of these traps contained a 50:50 mixture of water and antifreeze, which was replaced after each sampling. Insects were sampled every seven days; the canopy level of different crop patterns was uniformly netted, and pitfall traps were also checked on the same day, with samples collected from both methods. During each sampling phase, insects caught in the net and pit traps were stored separately in plastic containers and transported to the insect biosystematics laboratory at the Faculty of Agriculture, University of Kurdistan, noting the sampling date, cropping pattern type, and replication number.

After each sampling, specimens taken to the lab were cleaned of debris and non-target samples before being washed with a mixture of water and dishwashing liquid, followed by rinsing with distilled water to remove any antifreeze residues. Subsequently, ethanol at varying concentrations was utilized to dehydrate the samples, which were prepared for more specialized identification while retaining the characteristics of the relevant treatment (sampling date, type of cropping pattern, and replication number) to identify predatory insects using standard methods (Ghobari *et al*., 2014). Valid entomological keys (Triplehorn *et al*., 2005) were used systematically to identify predatory insects at the family level.

2.4. Statistical analysis and evaluation of biodiversity indicators

To analyze the data, normality tests were conducted using the Kolmogorov-Smirnov and Shapiro-Wilk tests. If the data did not meet the assumptions of normality, IBM SPSS Statistics Version 24 was used for normalization, and appropriate transformations were applied to each dataset. Subsequently, the data were statistically analyzed using a randomized complete block design (RCBD). Statistical analysis was performed with SAS Version 9 software, employing the LSD test for mean comparisons, while Excel software was used for creating graphs. Insect diversity indicators were assessed using Biodiversity Professional Version 2 software. To evaluate insect diversity, Shannon-Wiener's index (based on Equation 1; Shannon and Wiener, 1949) and Simpson's index (based on Equation 2; Simpson, 1949) were applied. Since diversity declines as D increases, Simpson's diversity index is often expressed as 1-D or 1/D (Ejtehadi *et al*., 2009). In this research, the inverse of Simpson's formula was used.

$$(1) \quad H = -\sum_{i=1}^{s} Pi \ log_{10} Pi$$

$$(2) \quad D = \sum_{i=1}^{s} Pi^2$$

Where H is the Shannon–Wiener biodiversity index, D is the Simpson biodiversity index, Pi is the proportion of individuals of a given species relative to the total number of individuals in the same habitat (n/N), and S is the total number of species.

3. Results and discussion

3.1. Abundance of predatory insects in cropping patterns

Among the samples identified using valid keys, five important families of natural enemies of pests were selected for the investigation of diversity and abundance: Syrphidae, Carabidae, Coccinellidae, Staphylinidae, and Chrysopidae. A total of 2,283 samples belonging to these five families were counted. The highest number of insects was found in the Chrysopidae family, while the lowest number was found in the Syrphidae family (Table 2).

Insects from the Carabidae family exhibited the greatest diversity, comprising 16 different species, with the largest number belonging to the species "*Curtonotus aulicus*". In contrast, all insects from the Syrphidae family were identified as "*Eupeodes corolla*", all insects from the Coccinellidae family were identified as "*Coccinella septempunctata*", all insects from the Staphylinidae family were identified as "*Ocypus olens*", and all insects from the Chrysopidae family were identified as "*Chrysoperla carnea*".

The abundance percentage of different families of predatory insects in each of the safflower and chickpea intercropping patterns is shown in Fig. 2.

Table 2. Abundance of predators in cropping patterns

Perdators	Count in different cropping patterns											Total
	1:0	0:1	4:4	2:2	1:1	3:1	1:3	20%I	20%II	40%I	40%II	
Syrphidae	28	19	25	23	22	21	20	21	25	25	22	251
Carabidae	17	37	30	27	47	31	23	15	30	31	43	331
Coccinellidae	33	32	37	37	43	29	33	35	36	41	34	390
Staphylinidae	33	38	58	31	42	49	32	37	40	28	38	426
Chrysopidae	111	25	64	92	123	66	50	111	83	107	53	885
Total	222	151	214	210	277	196	158	219	214	232	190	2283

1:0- monoculture of safflower, 0:1- monoculture of chickpea, 4:4- 4 rows of safflower and 4 rows of chickpea, 2:2- 2 rows of safflower and 2 rows of chickpea, 1:1- 1 row of safflower and 1 row of chickpea, 3:1- 3 rows of safflower and 1 row of chickpea, 1:3- 1 row of safflower and 3 rows of chickpea, 20%I- 20% chickpea between safflower rows, 20%II- 20% chickpea around safflower rows, 40%I- 40% chickpea between safflower rows, 40%II- 40% chickpea around safflower rows.

3.2. Comparison of cropping patterns in the attraction of Syrphidae insects

The results of the analysis of variance indicated that the different patterns of intercropping did not have a significant effect on the attraction of members of the Syrphidae family (Table 3). However, the comparison of averages showed that the highest number of Syrphidae members was found in the pure safflower cultivation pattern, with an average of 9.33 individuals, while the lowest number was present in the pure chickpea cultivation pattern, with an average of 6.33. Among the intercropping patterns, the highest number of individuals from this family was observed in the 40% I, 20% II, and 4:4 patterns, with insignificant differences among them, while the lowest number was found in the 1:3 cropping pattern (Table 4). Insects of the Syrphidae family are nectar-feeding flies attracted to flowers. Consequently, we observed their highest presence in sole cropping of safflower and their lowest presence in sole cropping of chickpea. Other researchers found plant diversity effective in increasing the number of Syrphidae species and reported their contribution to controlling aphid pests (Almdal and Costamagna, 2023).

3.3. Comparison of cropping patterns in the attraction of carabidae insects

The results of the data analysis showed that the effect of different patterns of intercropping on the recruitment of members of the Carabidae family was significant at the 1% probability level (Table 3). The comparison of averages indicates that the highest number of

Carabidae members was present in the 1:1 intercropping pattern, with an average of 21.67, while the lowest numbers were found in the 20% intercropping pattern and pure safflower cultivation, with averages of 11.67 and 12.33, respectively (Table 4). A study on species diversity and the relative abundance of insects in the intercropping of marigolds and chickpeas found that the highest relative density (density, not diversity) of natural predators occurred in the planting pattern of one row of marigolds and one row of chickpeas (Valizadegan, 2015). In an evaluation of intercropping barley with canola and barley with peas, the population of Carabidae predators increased compared to monoculture barley (Butts *et al*., 2003). In a study examining the insect population in the intercropping of wheat and beans, the abundance of Carabidae beetles was influenced by different intercropping patterns (Asiry, 2013). Additionally, research on the intercropping of clover with other forage plants showed that the number of Carabidae family members was higher in intercropping than in pure cultivation (Cai *et al*., 2010).

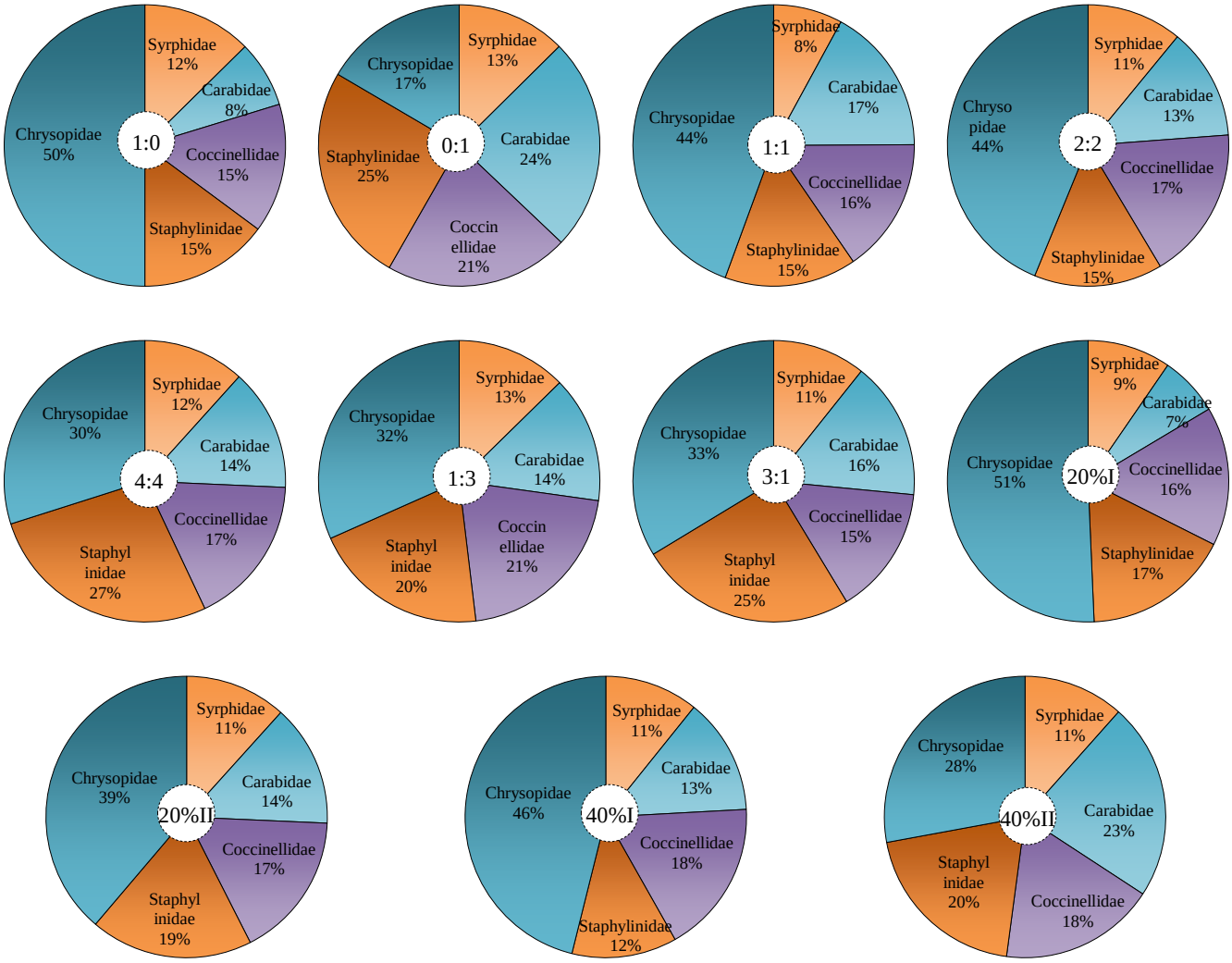


Figure 2. Percentage of predator insects in the cropping patterns of safflower and chickpea.

Table 3. Analysis of variance of the effect of cropping patterns on the abundance of predators

S.O.V	Df	Mean squares				
		Syrphidae	Carabidae	Coccinellidae	Staphylinidae	Chrysopidae
Replication	2	2.3^{ns}	7.18^{ns}	1.18^{ns}	1.73^{ns}	12.09**
Intercropping ratios	10	2.39^{ns}	32.46**	5.36**	24.87**	325.22**
Error	20	1.07	2.38	1.35	1.93	1.82
CV (%)		13.6	9.23	9.83	10.75	5.04

ns, * and **: Non-significant, significant at the 5 and 1 % levels of probability, respectively

Table 4. Means comparison of the effect of cropping patterns on the abundance of predators

Cropping patterns	Syrphidae	Carabidae	Coccinellidae	Staphylinidae	Chrysopidae
monoculture of safflower	9.33^{a}	12.33^{g}	11^{cd}	11^{def}	37^{b}
monoculture of chickpea	6.33^{c}	19^{bc}	10.67^{cd}	12.67^{cde}	8.33^{g}
4 rows of safflower and 4 rows of chickpea	8.33^{ab}	16.33^{de}	12.33^{bc}	19.33^{a}	21.33^{e}
2 rows of safflower and 2 rows of chickpea	7.67^{abc}	15.67^{ef}	12.33^{bc}	10.33^{ef}	30.67^{c}
1 row of safflower and 1 row of chickpea	7.33^{bc}	21.67^{a}	14.33^{a}	14^{bc}	41^{a}
3 rows of safflower and 1 row of chickpea	7^{bc}	18.67^{bcd}	9.67^{d}	16.33^{b}	22^{e}
1 row of safflower and 3 rows of chickpea	6.67^{bc}	13.67^{fg}	11^{cd}	10.67^{ef}	16.67^{f}
20% chickpea between safflower rows	7^{bc}	11.67^{g}	11.67^{c}	12.33^{cde}	37^{b}
20% chickpea around safflower rows	8.33^{ab}	17.67^{cde}	12^{bc}	13.33^{cd}	27.67^{d}
40% chickpea between safflower rows	8.33^{ab}	16.33^{de}	13.67^{ab}	9.33^{f}	35.67^{b}
40% chickpea around safflower rows	7.33^{bc}	21^{ab}	11.33^{cd}	12.67^{cde}	17.67^{f}

Means with similar letters are not significantly different at 5% level.

In our study, it seems that the presence of chickpeas in the planting patterns can create a modified microclimate, acting as a refuge that enhances the survival of natural enemies (Peterson *et al*., 2018; Yang *et al*., 2018). The remarkable effect of chickpea may be attributed to its canopy structure and lower height compared to safflower plants, which has significantly influenced the attraction of carabid beetles by providing a suitable shelter. The comparison between treatments shows the lowest number of carabid beetles in the sole cropping of safflower and the intercropping pattern 20%I, which had the fewest chickpea plants, supporting this inference. Furthermore, an examination of the results from other researchers also indicates a positive impact of intercropping on the population of carabid predators. For instance, in a study on intercropping of wheat and rapeseed, the population of carabidae predators was higher in all intercropping treatments compared to sole rapeseed cultivation (Hummel *et al*., 2012). In our study, consistent with the results of other research, the comparison of means indicates that the abundance of carabidae family members in all intercropping patterns (except for the 20%I pattern) was significantly higher than in the sole cropping of safflower. This suggests the potential importance of more diverse agricultural habitats for natural predators. Other researchers also found plant diversity effective in increasing the number of carabidae species and reported their contribution to controlling aphid pests (Järvinen *et al*., 2023).

3.4. Comparison of cropping patterns in attracting coccinellidae insects

The results of the data analysis showed that the effect of different intercropping patterns on attracting members of the Coccinellidae family was significant at the 1% probability level (Table 3). The comparison of averages indicates that the highest number of Coccinellidae individuals was found in the 1:1 replacement intercropping pattern, with an average of 14.33. This was followed by the 40% incremental intercropping pattern, which had an average of 13.67, while the least number was observed in the 3:1 cropping pattern, with an average of 9.67 (Table 4). In the intercropping of wheat and canola, the population of the Coccinellidae family was affected by different intercropping patterns (Dabbagh Mohammadi Nassab *et al*., 2013). Furthermore, intercropping beans and borage influenced the relative density and population of Coccinellidae insects (Koocheki *et al*., 2012). Rezaei Chiyaneh et al. (2014) reported the highest population of spotted ladybugs in a row intercropping of bean and dill plants, with the lowest population found in pure bean cultivation, which aligns with the results of this study. Other researchers found plant diversity effective in increasing the number of coccinellidae species and reported their contribution to controlling aphid pests (Almdal and Costamagna, 2023).

3.5. Comparison of cropping patterns in the attraction of staphylinidae insects

The results of the data analysis showed that the effect of different patterns of safflower and chickpea intercropping on the attraction of members of the Staphylinidae family was significant at the 1% probability level (Table 3). The comparison of averages indicated that the highest number of Staphylinidae members was present in the 4:4 cropping pattern, with an average of 19.33, followed by the 1:3 cropping pattern with an average of 16.33, while the lowest

number was found in the 40%I intercropping pattern, with an average of 9.33 (Table 4). In a study examining crop yield and insect diversity in different bean and dill intercropping patterns, the highest population (abundance, not diversity) of natural predators was observed in the intercropping with a ratio of 50% beans and 50% dill (Rezaei Chiyaneh *et al*., 2014). Additionally, an evaluation of insect populations in the intercropping of legumes with cereals indicated that the abundance of the Staphylinidae family of insects was affected by different intercropping patterns (Asiry, 2013). An older yet notable study found that the number of Staphylinidae predators was higher in the intercropping clover with weeds compared to cultivation without weeds (Altieri *et al*., 1985). Perhaps this is why researchers have stated that plots with high crop diversity supported higher species richness and greater abundance of predatory insects (Lucatero *et al*., 2024).

3.6. Comparison of cropping patterns in the attraction of chrysopidae insects

The results of the data analysis showed that the effect of different patterns of safflower and chickpea intercropping on the attraction of members of the Chrysopidae family was significant at the 1% probability level (Table 3). The investigation into insect populations in legume-grain intercropping revealed that the abundance of Chrysopidae family insects was influenced by various intercropping patterns (Asiry, 2013). The comparison of averages indicates that the highest number of Chrysopidae members was present in the 1:1 intercropping pattern, with an average of 41, while the lowest was found in the sole cropping of chickpea, with an average of 8.33 (Table 4). In a study on agricultural yield and insect diversity across different bean and dill intercropping patterns, the highest population of Chrysopidae insects was reported in the one-row intercropping pattern, with the lowest found in pure bean cultivation. This finding is consistent with results from this study (Rezaei Chiyaneh *et al*., 2014). Furthermore, evaluations of wheat and bean intercropping indicate that pure cultivation has the lowest population of Chrysopidae family members (Dabbagh Mohammadi Nassab *et al*., 2013). Researchers have inferred that neighboring crops provide alternative food sources, prey, and shelter for predators and parasites, thereby increasing the abundance and colonization of natural enemies (Gontijo, 2019).

3.7. Comparison of diversity of cropping patterns in terms of predatory insects

The Shannon-Wiener and Simpson indices were used to compare the cultivation patterns in terms of the biodiversity characteristics of predatory insects. The Shannon-Wiener and Simpson diversity indices for the families of predatory insects associated with each treatment were calculated using Biodiversity Professional Version 2 software. Although a high level of the Shannon-Wiener and Simpson indices in each cultivation pattern may indicate high diversity among the predatory insect population, these differences need to be statistically investigated. Therefore, the diversity index data were analyzed using a randomized complete block design with 11 treatments and 3 replications in SAS Version 9 software, and the differences between means were compared using the LSD test at the 1% probability level. The results of this study indicated that the cultivation patterns differed significantly in terms of the Shannon-Wiener and Simpson diversity indices at the 1% probability level regarding the diversity of predatory insects (Table 5).

The results of the present study showed that the diversity of predatory insects is higher in all intercropping treatments compared to pure safflower cultivation. This finding indicates that the intercropping patterns of safflower and chickpeas have increased the abundance of natural enemies compared to safflower monoculture. Plant diversity has been shown to be positively related to insect abundance and diversity and to ecosystem functions provided by insects (Lange *et al*., 2023). In a study on species diversity and the relative abundance of insects in the intercropping of marigold and chickpea, the lowest Shannon-Wiener index was obtained from pure marigold cultivation (Valizadegan, 2015). Additionally, in an evaluation of insect diversity in the intercropping of okra, tomato, and eggplant, the diversity of natural enemies from the families Carabidae, Coccinellidae, Staphylinidae, and Pentatomidae was influenced by different intercropping patterns; both the Shannon-Wiener and Simpson diversity indices were higher in all intercropping patterns compared to the pure cultivation of these plants (Anbalagan *et al*., 2016). Other

researchers have also noted that in their investigation of the intercropping of cabbage with garlic, the population increase of predatory insects led to a higher species diversity index compared to pure cultivation (Cai *et al*., 2010). The increase in the population of natural enemies in the intercropping of soybeans and wheatgrass, as opposed to pure cultivation, is another result reported by researchers. These researchers have stated that in intercropping, due to different ecological niches, variations in the chemical composition of plant tissues, and the production of aromatic compounds by the medicinal plant wormwood, the behavior of insects can be altered. This is because some of these compounds are attractive to insects while others are repellent (Lenardis *et al*., 2011).

Table 5. Analysis of variance of diversity of cropping patterns in terms of predator insects using Shannon-Wiener and Simpson indices

S.O.V	Df	Mean squares	
		Shannon-Wiener index	Simpson index
Replication	2	0.00005^{ns}	0.02^{ns}
Intercropping ratios	10	0.001**	0.53**
Error	20	0.00005	0.02
CV (%)		0.92	2.98

ns, * and **: Non-significant, significant at the 5 and 1 % levels of probability, respectively

The comparison of the average Shannon-Wiener index values showed that the sole cropping of chickpea, which includes 5 families and an abundance of 151, has the highest Shannon diversity index, with an average of 0.749. In contrast, the sole cropping of safflower, also with 5 families but an abundance of 222, has the lowest Shannon diversity index, with an average of 0.699. Among the intercropping treatments, the 3:1 and 1:3 patterns have the highest abundances of 196 and 158, with averages of 0.747 and 0.744, respectively. The 1:1 cultivation pattern, with an abundance of 277, has the lowest index level, averaging 0.72 (Fig. 3). The comparison of the average Simpson index values indicated that the pure cultivation pattern of chickpeas, with an average of 5.64, has the highest level of diversity, while the pure cultivation pattern of safflower, with an average of 4.45, has the lowest level of diversity. Among the different intercropping patterns, the 3:1 and 1:3 patterns, with averages of 5.57 and 5.43, respectively, demonstrated superiority over the other intercropping patterns. The 1:1 cropping pattern, with an average of 4.85, was at the lowest level (Fig. 4).

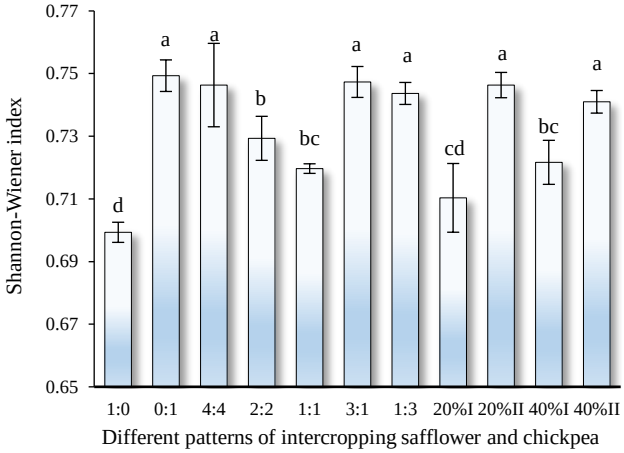


Figure 3. Means comparison of intercropping patterns in terms of the diversity of predator Insects based on the Shannon-Wiener index. 1:0- monoculture of safflower, 0:1- monoculture of chickpea, 4:4- 4 rows of safflower and 4 rows of chickpea, 2:2- 2 rows of safflower and 2 rows of chickpea, 1:1- 1 row of safflower and 1 row of chickpea, 3:1- 3 rows of safflower and 1 row of chickpea, 1:3- 1 row of safflower and 3 rows of chickpea, 20%I- 20% chickpea between safflower rows, 20%II- 20% chickpea around safflower rows, 40%I- 40% chickpea between safflower rows, 40%II- 40% chickpea around safflower rows.

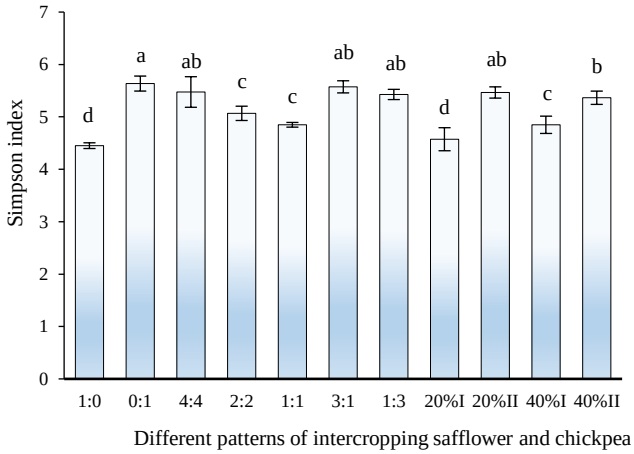


Figure 4. Means comparison of intercropping patterns in terms of the diversity of predator insects based on the Simpson index. 1:0- monoculture of safflower, 0:1- monoculture of chickpea, 4:4- 4 rows of safflower and 4 rows of chickpea, 2:2- 2 rows of safflower and 2 rows of chickpea, 1:1- 1 row of safflower and 1 row of chickpea, 3:1- 3 rows of safflower and 1 row of chickpea, 1:3- 1 row of safflower and 3 rows of chickpea, 20%I- 20% chickpea between safflower rows, 20%II- 20% chickpea around safflower rows, 40%I- 40% chickpea between safflower rows, 40%II- 40% chickpea around safflower rows.

The presence of two plant species in intercropping attracts beneficial insects, including natural enemies, thereby increasing insect species diversity. Intercropping can also enhance species diversity by providing resources and spatial and temporal opportunities for natural enemies. It appears that the presence of chickpeas in the intercropping has enhanced the diversity of natural enemies by creating a more varied habitat. In line with this, some researchers believe that intercropping can benefit natural enemies by providing diverse food sources and habitats, thereby

increasing their diversity within the ecosystem (Wang *et al*., 2009). Recent research results showed that intercropping soybeans and cotton increased the population and diversity of natural enemies (Mahendra *et al*., 2024). Researchers also reported that intercropping enhances natural enemy communities, facilitating pest suppression in plantations (Gong *et al*., 2024). In an investigation of intercropping Corn–Soybean, both the Shannon-Wiener diversity index and predator density were significantly higher than those observed in monoculture across all intercropping treatments, which is consistent with the results of the present study (Wei *et al*., 2025). In general, in agricultural ecosystems, plant diversity may favor natural enemies or interfere with the host-seeking behaviors of insect herbivores, leading to reduced pest populations and higher crop yields. Accordingly, plant diversity as a strategy for ecological pest management in many crops has been used (Rakotomalala *et al*., 2023).

4. Conclusion

The results of our study showed that safflower and chickpea intercropping increased the biodiversity of natural predators in agricultural ecosystems. In this study, we observed the highest natural predator populations and higher mean diversity indices in all intercropping patterns compared to safflower monocropping. Among the 11 different intercropping patterns evaluated in this study, the 1:3 and 3:1 replacement intercropping patterns emerged as the most effective options for ecological safflower cultivation and showed superior biodiversity indices compared to the other eight patterns.

Conflict of interests

The authors report there are no competing interests to declare.

Ethics approval and consent to participate

No humans or animals were used in the present research. The authors have adhered to ethical standards, including avoiding plagiarism, data fabrication, and double publication.

Consent for publications

All authors read and approved the final manuscript for publication.

Availability of data and material

All the data are embedded in the manuscript.

Authors' contributions

All authors had an equal role in study design, work, statistical analysis and manuscript writing.

Informed consent

The authors declare that no patients were used in this research.

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Generative AI statement

The author declares that generative AI (artificial intelligence) tools, including Grammarly & QuillBot, were used to enhance the language & clarity of this work. The author takes full responsibility for the accuracy & integrity of the content.

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