

Research Article

Biodiversity of Carabidae beetles improved in the intercropping system of safflower and chickpea

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Abstract: Intercropping is a sustainable agricultural system that resembles natural ecosystems. Biodiversity plays a vital role in the sustainability of intercropping systems. This study aimed to evaluate carabid beetle biodiversity in different safflower/chickpea intercropping patterns. The experiment was conducted in a randomized complete block design with 11 treatments and 3 replications at the research field of Kurdistan University. Experimental treatments included safflower sole cropping, chickpea sole cropping, a replacement series (4:4, 2:2, 1:1, 3:1, and 1:3), and an additive series (20% and 40% chickpea in two Situations: between and around safflower rows). In total, 16 Carabidae predator species were collected from Pitfall traps across the culture patterns, with *Curtonotus aulicus* being the most abundant. The results showed that intercropping significantly influenced Carabidae abundance. Rarefaction curves indicated that, for an equal number of sampled individuals, cropping patterns 1:3, 3:1, and 40%I had the highest Carabidae diversity, while 40%II and 4:4 had the lowest. Additionally, according to the Bray-Curtis similarity index, sole chickpea cultivation and the 1:1 pattern (76.19%), followed by the 3:1 and 40%I patterns (74.19%), showed the highest similarity in species diversity. Overall, the number of Carabidae species across all intercropping patterns was higher than in sole safflower, indicating a positive response of the Carabidae natural predator population to plant species diversity. However, Carabidae species responded differently to the various intercropping patterns in terms of diversity, richness, and abundance.

Keywords: Ecosystem service, Rarefaction curve, Similarity Bray-Curtis index, Shannon-Wiener index, Sustainable agriculture, Natural enemy

Introduction

In sustainable agriculture, habitat diversification helps reduce pests. Habitat heterogeneity in time and space often slows pest population buildup, either by reducing resource concentration or indirectly by changing predator and parasitoid numbers. Polycultures, including mixtures of

different crops and crops with noncrop vegetation, have been applied across a wide variety of crop types. Ecosystems can provide regulating services that change biodiversity patterns and ecological processes, and in turn affect the prevalence of crop pests. Biological pest control could serve as an environmentally friendly ecological control service to suppress crop pests and decrease

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pesticide use by maintaining or increasing natural enemies. However, few studies explicitly examine the processes of natural enemies, pest dynamics, quantitative assessment, and the mechanisms of ecological control services in multi-crop farmland landscape systems across the entire crop growing cycle (Ouyang *et al.*, 2020). Therefore, experts consider appropriate farming systems an effective strategy to increase sustainability, improve crop production, and strengthen food security worldwide. One of these cropping systems is intercropping systems that are inspired by nature and with goals such as ecological balance in crop ecosystems, better utilization of resources, quantitative and qualitative yield increase, yield stability under adverse environmental conditions, food supply without environmental contamination, and the reduction in chemical pesticide use, conditional on maintaining product quality (Thomine *et al.*, 2022). Increasing crop biodiversity, such as by strip intercropping, is recognized as an effective biological control measure. However, few studies have examined how strip intercropping increases natural enemy abundance, reduces pests, and subsequently reduces crop damage (Ju *et al.*, 2019). Therefore, many ecologists and entomologists advocate intercropping in integrated pest management systems to suppress insect pests (Hongjiao *et al.*, 2010). Humanity has always depended on the products and services ecosystems provide (Garcia *et al.*, 2018). Farmland ecosystems through crop production can provide a variety of foods to meet the escalating needs of the human population. But crop production usually suffers major losses to crop pests (Wan *et al.*, 2019).

Safflower (*Carthamus tinctorius* L.) is a multipurpose plant belonging to the Asteraceae family that is important in agronomic, industrial, and pharmaceutical aspects. Iran is one of the richest regions in the world for safflower genetic resources. This plant has the highest drought resistance among oilseed crops and can also be dry-farmed, which is a good option for cultivation given the country's water-crisis management issues. However, pests and diseases limit safflower seed yield. Chemical insecticides are commonly used to control pest damage in

safflower fields, but pesticide residues in the products and their impact on human health and the environment make it necessary to pay close attention to the methods and inputs used in production. This highlights the need to change current crop systems (Sabzalain *et al.*, 2010). On the other hand, limiting nitrogen fertilizer use has helped raise awareness of legume-rhizobia coexistence. Cultivating legumes is one of the most important strategies for stabilizing agronomic ecosystems, particularly by stabilizing atmospheric nitrogen (Jensen *et al.*, 2011).

The Carabidae family, or predator beetles, is one of the largest families of Coleoptera. This family is highly diverse across the world's habitats. These beetles are highly sensitive to environmental changes caused by human activities and are used as biological indicators in agricultural ecosystems. As polyphagous predators, they play an important role in natural pest control; unlike specialized predators, these beetles can survive and contribute to biological control when pest density is low. In sustainable agriculture, this self-regulation by predatory arthropods helps prevent pest outbreaks. Carabidae beetles, with more than 2000 genera and 40,000 species, are among the most diverse arthropods in agricultural ecosystems. The published list of Carabidae beetles in Iran includes 955 species. It includes 155 genera and 26 subfamilies. Carabidae larvae and adults are predators in almost all cases and are widely found in gardens and agricultural land as useful insects (Yafa'i *et al.*, 2016).

In sustainable farming systems, biodiversity facilitates natural self-regulation processes such as pest control and nutrient cycling, but monoculture disrupts these self-regulatory features and becomes an input-dependent system (Altieri, 1999). In the context of organic safflower production, it is necessary to develop effective biodiversity control approaches (Röös *et al.*, 2018). Intercropping is a sustainable agricultural system that preserves and enhances biodiversity (Baidoo *et al.*, 2012). Biodiversity assessment is one of the most important factors in determining ecosystem health and a key criterion for assessing habitat importance. Evaluating ecological indices provides

a clear picture of an ecosystem's environmental status and stability (Jorgenson *et al.*, 2005). In fact, as biodiversity increases and interactions among organisms become more complex, food chains lengthen, and networks become more complex; in other words, the greater the biodiversity of an ecosystem, the longer the food chains and the more complex the networks, and thus the more stable and self-regulated the environment. As a result, biodiversity in any ecosystem is key to sustainability and environmental health (Wilkinson, 2000). Other researchers have also reported that Carabidae beetle diversity increased in maize and bean intercropping (Hüber *et al.*, 2022). Carabidae beetle diversity also increased in wheat and oilseed rape intercropping (Alarcón-Segura *et al.*, 2022). The researchers suggested that intercropping shifts the balance between carabid predators and oilseed pests towards natural pest control (Järvinen *et al.*, 2023).

However, due to limited published information and results on the biodiversity status of the safflower and chickpea intercropping system, in the present study, the evaluation of biodiversity characteristics of the ecosystem as one of the most important ecological indicators to determine the importance, health, and stability of an ecosystem in intercropping patterns of safflower and chickpea was considered. The

density and diversity of predatory beetles of the Carabidae family, as biomarkers sensitive to human activities, were used as the criterion for this evaluation.

Materials and Methods

The study was conducted at the Kurdistan University research farm in 2017, located 45 km east of Sanandaj city at 35°05 ' N, 47°18 ' E, and 1865 meters above sea level. Safflower seeds from the Sina cultivar (PI-537598) and chickpea seeds from the Dessi type were the most successful cultivars and were cultivated in spring. The experiment followed a randomized complete block design with 11 treatments and 3 replications. Experimental treatments consisted of different cultivation patterns including sole cropping of safflower and chickpea plants, replacement intercropping with 4:4, 2:2, 1:1, 3:1, 1:3, and 20% additive intercropping of chickpea with two planting arrangements 20%I (20% chickpea between safflower rows) and 20%II (20% chickpea around safflower rows), as well as 40% incremental intercropping of chickpea with two 40%I (40% chickpea pea intercropping) and 40%II (40% of chickpeas were around the safflower rows). The schematic scheme of cropping patterns is presented in Fig. 1.

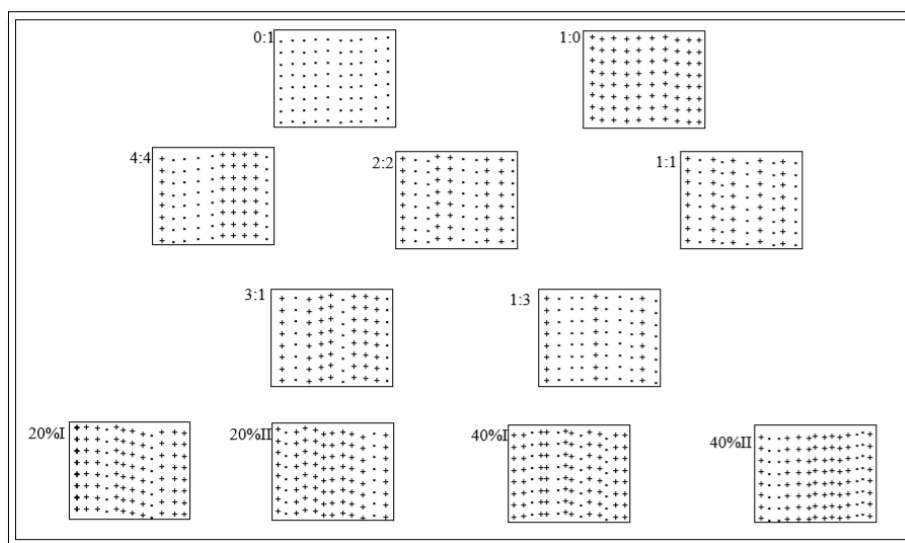


Figure 1 Schematic Figure of different Sole cropping and intercropping patterns of safflower and chickpea.
+: safflower, •: chickpea.

Row spacing was 35 and 10 cm in sole cropping, respectively. In each block, plots were 4 m apart, and blocks were 5 m apart, so adjacent plots did not overlap during the insect-population study. We weeded manually during the growing season as needed, based on soil test results (Table 1) and the need to support safflower growth, test experiments under sustainable conditions, and avoid interference with insect abundance and diversity. During soil preparation and plant growth, no fertilizers or pesticides were applied in the treatments. Thinning was also carried out to achieve optimal plant density at the 4-6 foliation stage.

Table 1 Physical and chemical properties of site soil.

Clay (%)	42.8
Sand (%)	12.3
Silt (%)	44.9
C (%)	1
N (%)	0.11
P (ppm)	13
K (ppm)	406
EC (Ds/m)	0.4
pH	7.72

To collect and estimate the abundance and diversity of Carabidae populations and their predators in various mixed-cropping patterns of safflower and chickpeas, sampling was conducted from canopy formation to harvest by placing pitfall traps in the soil (Borror and Delong, 2005). The pitfall trap was 20 cm deep and 15 cm in diameter (Duelli *et al.*, 1999), covered with a metal mesh to prevent entry by small rodents and amphibians, and topped with plastic containers to prevent rainwater from entering. In each plot, three traps were placed and numbered for ease of management. We filled one-third of each trap with a 50:50 water-antifreeze solution, which we replaced after each sampling. We checked the pitfall traps every 7 days and collected the trapped samples. We then prepared the traps again to capture new samples; after collecting the insects, we replaced the 50:50 water-antifreeze solution and set the traps back in their original locations. During each

sampling phase, we placed the trapped samples from the pitfall traps in separate plastic containers, labeled with the sampling date, cropping pattern, and replicate number, and transferred them to the Insect Biosystematics Laboratory at the Faculty of Agriculture, University of Kurdistan. After each sampling, samples transferred to the laboratory were first washed with a mixture of water and dishwashing liquid to remove antifreeze, then rinsed with distilled water. Subsequently, to dehydrate the samples, ethanol at various concentrations was used, and after initial separation and identification of the insects, the prepared samples were subjected to standard methods for mounting and preserved with their respective treatment details (sampling date, type of cropping pattern, and replicate number) for further specialized studies and identification of Carabidae species (Ghobari *et al.*, 2013). After identifying the species, we statistically analyzed the data using a randomized complete block design (RCBD). We used SAS Version 9 for statistical analysis, applied the LSD test for mean comparisons, and used Excel for graphing. Diversity indices were evaluated using Biodiversity Professional Version 2 software. To assess carabid diversity, we calculated the Shannon-Wiener index using Equation 1 (Shannon and Wiener, 1949) and the Simpson index using Equation 2 (Simpson, 1949). Since diversity decreases as D increases, the Simpson diversity index is typically expressed as 1-D or 1/D. In this study, the inverse of the Simpson formula was also used.

$$H = -\sum_{i=1}^S P_i \log_{10} P_i \text{ (Equation 1)}$$

$$D = \sum_{i=1}^S P_i^2 \text{ (Equation 2)}$$

H: Shannon-Weiner biodiversity index

D: Simpson biodiversity index

P_i: The proportion of individuals of all species in the same habitat (n/N)

S: Number of species

One challenge often encountered when comparing communities for which the number of species has been determined through sampling is that it is not always possible to have an equal number of samples in the communities being

compared. For instance, if one community has 12 species and 210 individuals, while another has 7 species and 70 individuals, one cannot quickly conclude which community has greater species richness. One way to overcome this issue is to standardize sampling units across communities to a uniform size with a similar number of individuals (Sanders, 1968). The Rarefaction method was suggested to achieve this goal. The rarefaction method is a statistical approach for estimating the expected number of species from a randomly selected group of individuals in a sample. Essentially, this method answers: if a sample contains n individuals, how many species (s) are likely to be present?

Therefore, to estimate species diversity in the Carabidae family in samples collected from each cultivation pattern, we used rarefaction. Using Biodiversity Professional Version 2, we examined the number of Carabidae species present in each cropping pattern by abundance. The Bray-Curtis similarity index is used in biodiversity studies to calculate the degree of similarity or dissimilarity between samples and

communities. This index is designed so that complete similarity between two sets equals one, and no similarity equals zero. To calculate this index to examine similarity among cropping patterns in terms of Carabidae species diversity, Biodiversity Professional Version 2 software was used.

Results

Comparison of different cropping patterns in Carabidae family abundance

Data analysis showed that different intercropping patterns significantly affected Carabidae family abundance (df treatment = 10, df error = 20, $F = 13.63$, $P < .0001$). Comparisons of means indicate that the abundance of the Carabidae family in all intercropping patterns (except 20%I) was higher than in pure safflower. Most Carabidae were in the 1:1 blend pattern, with a mean of 21.67, and the lowest in the I20% and pure safflower blend patterns, with means of 11.67 and 12.33, respectively (Fig. 2).

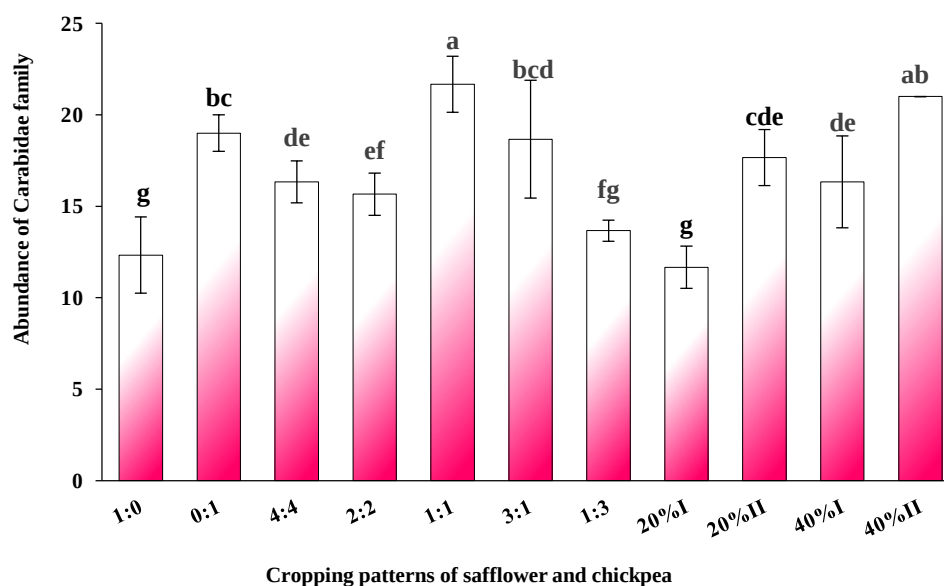


Figure 2 Means comparison of the effect of cropping patterns on abundance of the Carabidae family.

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 rows of safflower and 1 rows of chickpea, 3:1- 3 rows of safflower and 1 rows of chickpea, 1:3- 1 rows 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 and 40%II- 40% chickpea around safflower rows.

Identification of Carabidae family species in cropping patterns

Species identification revealed that, of all collected insects, 331 belonged to the family Carabidae, representing 16 species. The highest number of samples in this family belonged to species 8 (*Curtonotus aulicus*: Panzer, 1796), while species 1, 9, 14, 15, and 16 were among the rarest individuals of the Carabidae family (Fig. 3).

Comparison of different cropping patterns of safflower and chickpea in the attraction of Carabidae species

Analysis of variance showed no significant difference in Carabidae species uptake

among intercropping patterns (Table 2). Comparative results show, in greater detail, the effect of different safflower and chickpea cropping patterns on the absorption of each Carabidae species (Table 3).

Investigation of biodiversity characteristics of Carabidae species

To compare cropping patterns in terms of Carabidae biodiversity characteristics, we used the Shannon-Wiener and Simpson indices. The Shannon-Wiener and Simpson diversity indices for Carabidae in each treatment were calculated using Biodiversity Professional Version 2 software.

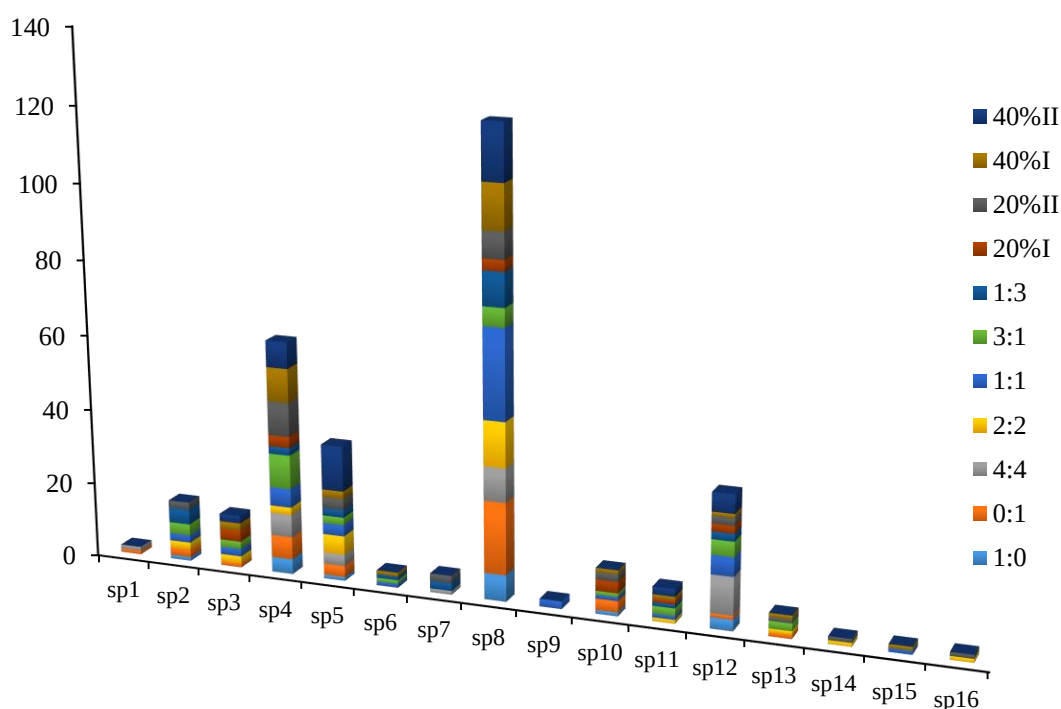


Figure 3 Abundance of Carabidae species in cropping patterns.

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 rows of safflower and 1 rows of chickpea, 3:1- 3 rows of safflower and 1 rows of chickpea, 1:3- 1 rows 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 and 40%II- 40% chickpea around safflower rows.

SP1- *Harpalus rufipes*, SP2- *Lebia cyanocephala*, SP3- *Tschitscherinellus oxygonus*, SP4- *Calathus cinctus*, SP5- *Harpalus affinis*, SP6- *Lebia cruxminor*, SP7- *Distichus planus*, SP8- *Curtonotus aulicus*, SP9- *Drypta dentata*, SP10- *Amara eurynota*, SP11- *Calathus syriacus*, SP12- *Amara aenea*, SP13- *Calathus halensis*, SP14- *Broscus cephalotes*, SP15- *Acinopus picipes* and SP16- *Bembidion properans*.

An examination of the biodiversity characteristics of the Carabidae family, which included 16 species and a total abundance of 331, revealed that by calculating species richness, abundance, and the Shannon-Wiener and Simpson diversity indices, the 20% intercropping pattern and pure safflower, with a

species richness of 6 and abundances of 15 and 17, respectively, recorded the highest Shannon-Wiener diversity indices of 1.16 and 1.153. In contrast, the 1:1 intercropping pattern, with a species richness of 11 and an abundance of 47, had the lowest Shannon-Wiener index (1.058; Fig. 4).

Table 2 Mean squares of cropping patterns' effect on abundance of Carabidae species.

Source of variation	df	sp1	sp2	sp3	sp4	sp5	sp6	sp7	sp8	sp9	sp10	sp11	sp12	sp13	sp14	sp15	sp16
Replication	2	0.03 ^{ns}	0.39 ^{ns}	0.39 ^{ns}	7.85 ^{ns}	3.91 [*]	0.49 [*]	0.12 ^{ns}	21.85 ^{ns}	0.12 ^{ns}	0.64 ^{ns}	0.09 ^{ns}	2.03 ^{ns}	0.09 ^{ns}	0.03 ^{ns}	0.03 ^{ns}	0.12 ^{ns}
Intercropping ratios	10	0.06 ^{ns}	0.62 ^{ns}	0.41 ^{ns}	2.69 ^{ns}	3.34 ^{**}	0.09 ^{ns}	0.22 [*]	13.03 ^{**}	0.12 ^{ns}	0.43 ^{ns}	0.19 ^{ns}	2.59 [*]	0.16 ^{ns}	0.06 ^{ns}	0.06 ^{ns}	0.06 ^{ns}
Error	20	0.06	1.36	0.36	3.25	0.88	0.09	0.09	8.45	0.12	0.8	0.32	1.6	0.16	0.06	0.06	0.06
CV (%)		23.79	78.56	42.16	62.61	44.76	25.98	25.74	30.6	32.83	65.72	44.74	61.33	33.59	23.79	23.79	22.02

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

SP1- *Harpalus rufipes*, SP2- *Lebia cyanocephala*, SP3- *Tschitscherinellus oxygonus*, SP4- *Calathus cinctus*, SP5- *Harpalus affinis*, SP6- *Lebia cruxminor*, SP7- *Distichus planus*, SP8- *Curtonotus aulicus*, SP9- *Drypta dentata*, SP10- *Amara eurynota*, SP11- *Calathus syriacus*, SP12- *Amara aenea*, SP13- *Calathus halensis*, SP14- *Broscus cephalotes*, SP15- *Acinopus picipes* and SP16- *Bembidion properans*.

Table 3 Means comparison of the effect of cropping patterns on the abundance of Carabidae species.

Intercropping Patterns	Carabidae species															
	sp1	sp2	sp3	sp4	sp5	sp6	sp7	sp8	sp9	sp10	sp11	sp12	sp13	sp14	sp15	sp16
1:0	0 ^a	0.33 ^a	0 ^a	1.33 ^a	0.33 ^{bc}	0 ^a	0 ^b	2.33 ^{bc}	0 ^b	0.33 ^a	0 ^a	1 ^b	0 ^a	0 ^a	0 ^a	0 ^a
0:1	0.33 ^a	0.67 ^a	0.33 ^a	2 ^a	1 ^{bc}	0 ^a	0 ^b	6.33 ^{ab}	0 ^b	1 ^a	0 ^a	0.33 ^b	0.33 ^a	0 ^a	0 ^a	0 ^a
4:4	0.33 ^a	0 ^a	0 ^a	1.67 ^a	1 ^{bc}	0 ^a	0.33 ^{ab}	3 ^{bc}	0 ^b	0 ^a	0 ^a	3.33 ^a	0 ^a	0 ^a	0 ^a	0 ^a
2:2	0 ^a	0.67 ^a	0.67 ^a	0.67 ^a	1.67 ^b	0 ^a	0 ^b	4 ^{abc}	0 ^b	0 ^a	0.33 ^a	0 ^b	0.33 ^a	0.33 ^a	0 ^a	0.33 ^a
1:1	0 ^a	0.67 ^a	0.67 ^a	1.67 ^a	1 ^{bc}	0.33 ^a	0 ^b	8 ^a	0.67 ^a	0.33 ^a	0.33 ^a	1.67 ^{ab}	0 ^a	0 ^a	0.33 ^a	0 ^a
3:1	0 ^a	1 ^a	0.67 ^a	3 ^a	0.67 ^{bc}	0.33 ^a	0 ^b	1.67 ^{bc}	0 ^b	0.33 ^a	0.67 ^a	1.33 ^{ab}	0.67 ^a	0 ^a	0 ^a	0 ^a
1:3	0 ^a	1.33 ^a	0 ^a	0.67 ^a	0.67 ^{bc}	0.33 ^a	0.67 ^a	3 ^{bc}	0 ^b	0 ^a	0.33 ^a	0.67 ^b	0 ^a	0 ^a	0 ^a	0 ^a
20%I	0 ^a	0 ^a	1 ^a	1 ^a	0 ^c	0 ^a	0 ^b	1 ^c	0 ^b	1 ^a	0.33 ^a	0.67 ^b	0 ^a	0 ^a	0 ^a	0 ^a
20%II	0 ^a	0.67 ^a	0 ^a	3.33 ^a	1 ^{bc}	0 ^a	0.67 ^a	2.33 ^{bc}	0 ^b	0.67 ^a	0 ^a	0.67 ^b	0.33 ^a	0.33 ^a	0 ^a	0.33 ^a
40%I	0 ^a	0 ^a	0.67 ^a	3 ^a	0.67 ^{bc}	0.33 ^a	0 ^b	4 ^{abc}	0 ^b	0.33 ^a	0.33 ^a	0.33 ^b	0.33 ^a	0 ^a	0.33 ^a	0 ^a
40%II	0 ^a	0 ^a	0.67 ^a	2.33 ^a	4 ^a	0 ^a	0 ^b	5 ^{abc}	0 ^b	0 ^a	0.67 ^a	1.67 ^{ab}	0 ^a	0 ^a	0 ^a	0 ^a

In each column, averages with at least one common letter do not differ significantly at the 5% probability level based on the LSD test.

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 rows of safflower and 1 rows of chickpea, 3:1- 3 rows of safflower and 1 rows of chickpea, 1:3- 1 rows 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 and 40%II- 40% chickpea around safflower rows.

SP1- *Harpalus rufipes*, SP2- *Lebia cyanocephala*, SP3- *Tschitscherinellus oxygonus*, SP4- *Calathus cinctus*, SP5- *Harpalus affinis*, SP6- *Lebia cruxminor*, SP7- *Distichus planus*, SP8- *Curtonotus aulicus*, SP9- *Drypta dentata*, SP10- *Amara eurynota*, SP11- *Calathus syriacus*, SP12- *Amara aenea*, SP13- *Calathus halensis*, SP14- *Broscus cephalotes*, SP15- *Acinopus picipes* and SP16- *Bembidion properans*.

Simpson diversity index calculations across treatments also indicated that the 20% intercropping pattern and sole safflower cropping had the highest Simpson index, while the 1:1 mixed cropping pattern had the lowest (Fig. 5).

Although high values of the Shannon-Wiener and Simpson indices in each cropping pattern may indicate high diversity within the Carabidae population of that cropping pattern, it was necessary to analyze these differences statistically. Therefore, we analyzed the diversity-index data using a completely randomized block design with 11 treatments and 3 replications in SAS Version 9 and compared mean differences using the LSD test at a 5% significance level. The results showed no significant differences in Carabidae species

diversity among cropping patterns based on both the Shannon-Wiener and Simpson indices (Table 4).

Using a rarefaction curve to estimate the species diversity of Carabidae predators in intercropping patterns of safflower and chickpea

According to the rarefaction diagram for 1:3, 3:1, and I40%, the lowest number of species was observed at the lowest number of species, whereas in the II40 % and 4:4, the lowest number of species was observed at the highest number of samples. In other words, 1:3, 3:1, and 40%I cultivars had the highest diversity, and II40% and 4:4 cultivars had the least diversity in terms of Carabidae predators (Fig. 6).

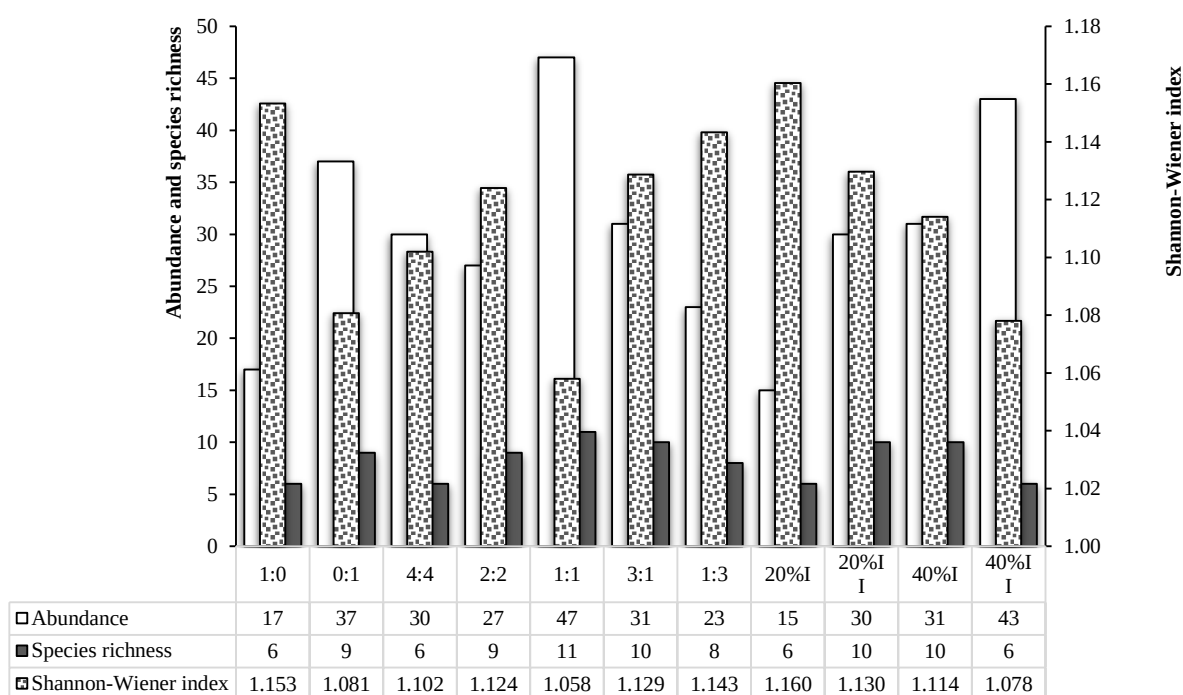


Figure 4 Species richness, abundance, and diversity index of Shannon-Wiener in the family Carabidae in cropping patterns.

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 rows of safflower and 1 rows of chickpea, 3:1- 3 rows of safflower and 1 rows of chickpea, 1:3- 1 rows 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 and 40%II- 40% chickpea around safflower rows.

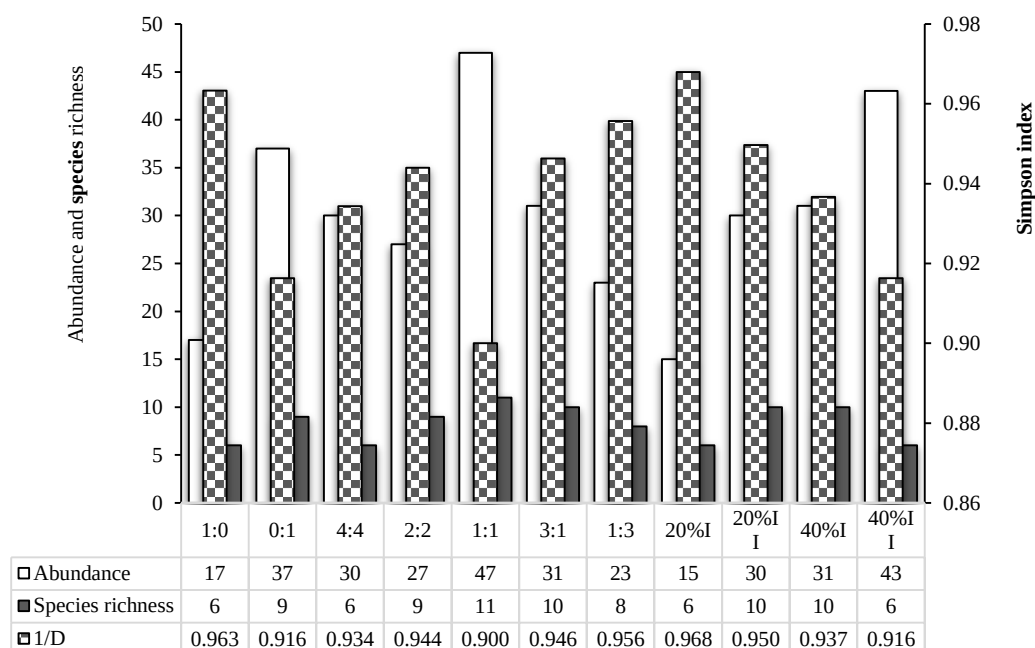


Figure 5 Species richness, abundance, and diversity index of the family Carabidae in cropping patterns. 1:0- monoculture of safflower, 0:1- monoculture of chickpea, 4:4- 4 rows of safflower and 4 rows of chickpea, 2:2- 2 rows of safflower and 2 rows of chickpea, 1:1- 1 rows of safflower and 1 rows of chickpea, 3:1- 3 rows of safflower and 1 rows of chickpea, 1:3- 1 rows 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 and 40%II- 40% chickpea around safflower rows.

Table 4 Analysis of variance of diversity of cropping patterns in terms of Carabidae species using Shannon-Wiener and Simpson indices.

S.O.V	Df	Mean squares	
		Shannon-Wiener index	Simpson index
Replication	2	0.01 ^{ns}	0.003 ^{ns}
Intercropping patterns	10	0.003 ^{ns}	0.001 ^{ns}
Error	20	0.003	0.001
CV (%)		4.99	3.7

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

Examining the similarity of intercropping patterns of safflower and chickpeas in terms of the composition of Carabidae species

We constructed a similarity dendrogram to examine similarity among cropping patterns based on Carabidae species composition. To create this dendrogram, the Bray-Curtis similarity index was utilized in the Biodiversity Professional Version 2 software. The results

indicated that, in terms of Carabidae species composition, the sole chickpea cropping pattern and the 1:1 intercropping pattern showed the highest species-diversity similarity (76.19%), followed closely by the 3:1 replacement intercropping pattern and the 40%I additive intercropping pattern (74.19%). The 20%I treatment differed most from the other intercropping treatments in Carabidae species composition (Fig. 7 and Table 5).

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 rows of safflower and 1 rows of chickpea, 3:1- 3 rows of safflower and 1 rows of chickpea, 1:3- 1 rows 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 and 40%II- 40% chickpea around safflower rows.

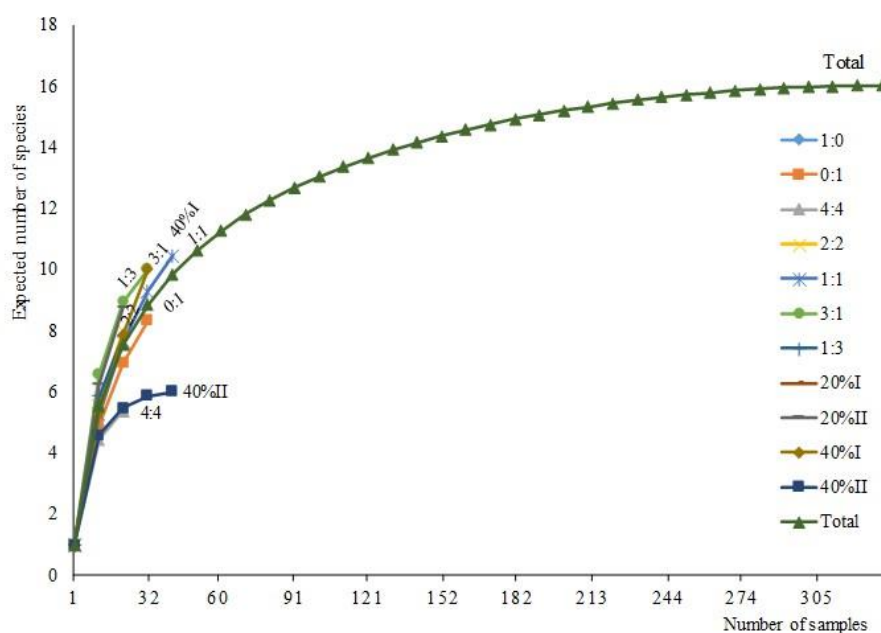


Figure 6 Estimation of species diversity of Carabidae predators in cropping patterns.

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 rows of safflower and 1 rows of chickpea, 3:1- 3 rows of safflower and 1 rows of chickpea, 1:3- 1 rows 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 and 40%II- 40% chickpea around safflower rows.

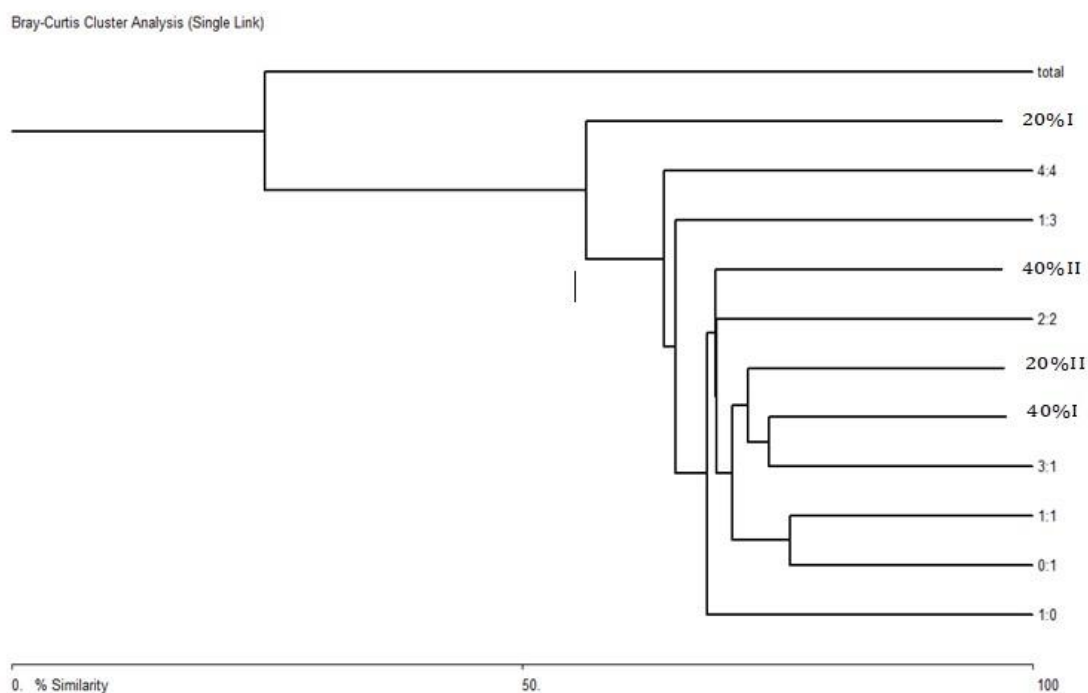


Figure 7 Dendrogram similarity of cropping patterns in terms of the composition of Carabidae species based on Bray-Curtis similarity index.

Table 5 Similarity percentage of cropping patterns in terms of Carabidae species composition based on the Bray-Curtis similarity index.

	1:0	0:1	4:4	2:2	1:1	3:1	1:3	20%I	20%II	40%I	40%II	Total
1:0	*	55.56	63.83	50	53.13	62.5	65	56.25	68.09	58.33	50	9.77
0:1	*	*	59.7	65.63	76.19	55.88	53.33	42.31	65.67	70.59	65	20.11
4:4	*	*	*	49.12	57.14	55.74	60.38	35.56	63.33	59.02	63.01	16.62
2:2	*	*	*	*	59.46	51.72	64	38.1	59.65	68.97	62.86	15.08
1:1	*	*	*	*	*	58.97	54.29	38.71	51.95	66.67	68.89	24.87
3:1	*	*	*	*	*	*	59.26	52.17	72.13	74.19	59.46	17.13
1:3	*	*	*	*	*	*	*	42.11	64.15	59.26	48.48	12.99
20%I	*	*	*	*	*	*	*	*	44.44	47.83	37.93	8.67
20%II	*	*	*	*	*	*	*	*	*	68.85	52.05	16.62
40%I	*	*	*	*	*	*	*	*	*	*	67.57	17.13
40%II	*	*	*	*	*	*	*	*	*	*	*	22.99
Total	*	*	*	*	*	*	*	*	*	*	*	*

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 rows of safflower and 1 rows of chickpea, 3:1- 3 rows of safflower and 1 rows of chickpea, 1:3- 1 rows 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 and 40%II- 40% chickpea around safflower rows.

Discussion

In agricultural ecosystems, plant diversity may favor natural enemies or interfere with the host-seeking behaviors of insect herbivores, reducing pest populations and increasing crop yields. Accordingly, plant diversity as a strategy for ecological pest management has been used in many crops (Rakotomalala *et al.*, 2023). Plant diversity is positively related to insect abundance and diversity and to insect-provided ecosystem functions (Lange *et al.*, 2023). Researchers found that plant diversity increases the number of Coccinellidae and Syrphidae species and reported their contribution to controlling aphid pests (Almdal and Costamagna, 2023). The same result has been reported for carabid predators and oilseed pest control (Järvinen *et al.*, 2023). Studies have shown that plots with high crop diversity supported higher species richness and greater abundance of predatory insects (Lucatero *et al.*, 2024). 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). (Gontijo, 2019). In this regard, intercropping soybean and wormwood has been reported to increase natural-enemy populations and

decrease pest populations compared with monoculture (Lenardis *et al.*, 2011). These researchers stated that, in intercropping, different ecological niches, variations in the chemical composition of plant tissues, and the production of aromatic compounds by the medicinal plant wormwood can alter insect behavior. This is because some of these compounds attract insects, while others repel them. In our study, consistent with other research, mean comparisons indicate that Carabidae abundance in all intercropping patterns (except the 20%I pattern) was significantly higher than in safflower monoculture. This suggests that more diverse agricultural habitats may be important for natural predators.

The presence of chickpeas in the planting patterns may 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 significantly influenced carabid beetle attraction by providing suitable shelter. The comparison between treatments shows the lowest number of carabid beetles in safflower monocropping and in intercropping pattern 20%I, which had the fewest chickpea plants,

supporting this inference. Furthermore, results from other researchers also indicate a positive impact of intercropping on carabid predator populations. For instance, in a study on intercropping wheat and rapeseed, Carabidae predator populations were higher in all intercropping treatments than in sole rapeseed cultivation (Hummel *et al.*, 2012). In a study of insect populations in the intercropping of wheat and fava beans, the abundance of Carabidae beetles was influenced by different intercropping patterns (Asiry, 2013), and in an investigation of mixed clover with other forage plants, the number of Carabidae family members was higher in intercropping compared to sole cropping (Hongjiao *et al.*, 2010).

Some researchers suggest that intercropping moderates the microclimate and maintains relative humidity, resulting in a canopy that is often cooler and more humid. This supports the establishment and persistence of natural enemies. Additionally, intercropping increases natural-enemy populations by providing diverse food resources and multiple habitats (Wanlei *et al.*, 2009). 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. 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).

The difference between our research and the comparative studies is that our study focused on a particular type of natural predator, namely Carabidae beetles, rather than several different types of predators. For this reason, our variance analysis showed that the different intercropping patterns did not differ significantly in attracting Carabidae species. This finding suggests that the biodiversity structure of cropping patterns regarding Carabidae species is almost similar, indicating the influence and close relationship

among Carabidae predator communities across all studied cropping patterns. Given the relatively similar feeding habits of Carabidae predators and the relatively low diversity of artificial agricultural ecosystems, this is not unexpected and seems quite logical. Other studies have noted that several Carabidae species are strongly associated with specific habitats (Gobbi and Fontaneto, 2008). Another reason for this non-significance may be the high diversity of the experimental treatments.

Conclusion

The results indicated that different intercropping patterns significantly affected the abundance of Carabidae family members at the 1% probability level. Although the cropping patterns did not show significant differences in the species diversity of Carabidae predators, the rarefaction curves revealed that, with an equal number of sampled individuals, the 1:3, 3:1, and 40%I cropping patterns exhibited the highest species diversity, while 40%II and 4:4 showed the lowest diversity in terms of Carabidae predators. Additionally, according to the Bray-Curtis similarity index, sole chickpea cropping and 1:1 intercropping showed the highest species-diversity similarity (76.19%), followed by 3:1 replacement intercropping and 40%I additive cropping (74.19%). Overall, the findings indicated that different intercropping patterns influenced the ecosystem's ecological characteristics, including insect abundance, composition, and diversity. The number of Carabidae family members in all intercropping patterns was higher than in the sole cropping of safflower, indicating a positive response of the population of natural predators (Carabidae) to plant species diversity. However, Carabidae species responded differently to intercropping patterns in terms of diversity, richness, and abundance. Consequently, chickpea strips in the cropping pattern can serve as habitat for natural enemies and suppress safflower pests. In other words, increased populations of polyphagous Carabidae predators in safflower-chickpea intercropping increase pressure on certain pest

populations and suppress them. Because safflower is one of the plants sensitive to pests, these findings support the potential of intercropping systems to reduce dependence on pesticides in safflower medicinal plant production.

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تنوع زیستی شکارگران Carabidae در سیستم کشت مخلوط گلرنگ و نخود بهبود یافت

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چکیده: سیستم کشت مخلوط یکی از سیستم‌های کشاورزی پایدار است که شبیه اکوسیستم‌های طبیعی است. تنوع زیستی نقش حیاتی در پایداری سیستم‌های کشت مخلوط ایفا می‌کند. هدف از این مطالعه بررسی تنوع زیستی سوسک‌های Carabidae در الگوهای مختلف کشت مخلوط گلرنگ و نخود بود. آزمایش در قالب طرح بلوک‌های کامل تصادفی با ۱۱ تیمار و ۳ تکرار در مزرعه تحقیقاتی دانشگاه کردستان اجرا شد. تیمارهای آزمایشی شامل کشت خالص گلرنگ، کشت خالص نخود، سری‌های جایگزینی ۴:۴، ۲:۲، ۱:۱، ۳:۱ و ۱:۳ و سری‌های افزایشی ۲۰٪ و ۴۰٪ نخود هر کدام در دو حالت بین (I) و اطراف (II) ردیف‌های گلرنگ بودند. در مجموع، ۱۶ گونه از شکارگران Carabidae توسط تله‌های Pitfall از الگوهای کشت جمع‌آوری شد که *Curtonotus aulicus* فراوان‌ترین گونه است. نتایج نشان داد که تأثیر الگوهای مختلف کشت مخلوط بر فراوانی خانواده Carabidae معنی‌دار بود. بیش‌ترین مقدار تنوع گونه‌ای شکارگران Carabidae از الگوهای کشت مخلوط ۱:۳، ۳:۱ و ۴۰٪I و کم‌ترین مقدار آن‌ها از الگوهای ۴۰٪II و ۴:۴ به دست آمد. همچنین، براساس شاخص شباهت بری-کارتیس، کشت خالص نخود و الگوی کشت مخلوط ۱:۱ (۷۶/۱۹٪) و سپس الگوی ۳:۱ و ۴۰٪I (۷۴/۱۹٪) بیش‌ترین شباهت تنوع گونه‌ای را نشان دادند. به‌طور کلی، تعداد افراد خانواده Carabidae در تمامی الگوهای کشت مخلوط بیش‌تر از کشت خالص گلرنگ بود و این به معنی پاسخ مثبت جمعیت شکارگران طبیعی Carabidae به تنوع گونه‌های گیاهی است. با این حال، گونه‌های Carabidae از نظر تنوع، غنا و فراوانی به الگوهای کشت مخلوط واکنش‌های متفاوتی نشان دادند.

واژگان کلیدی: خدمات اکوسیستمی، منحنی ریرفکشن، شاخص تشابه بری-کارتیس، شاخص شانون-

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