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Impact of Flowering Plant Heterogeneity on Enhancing Population Abundance of Arthropod Predators and Pollinators

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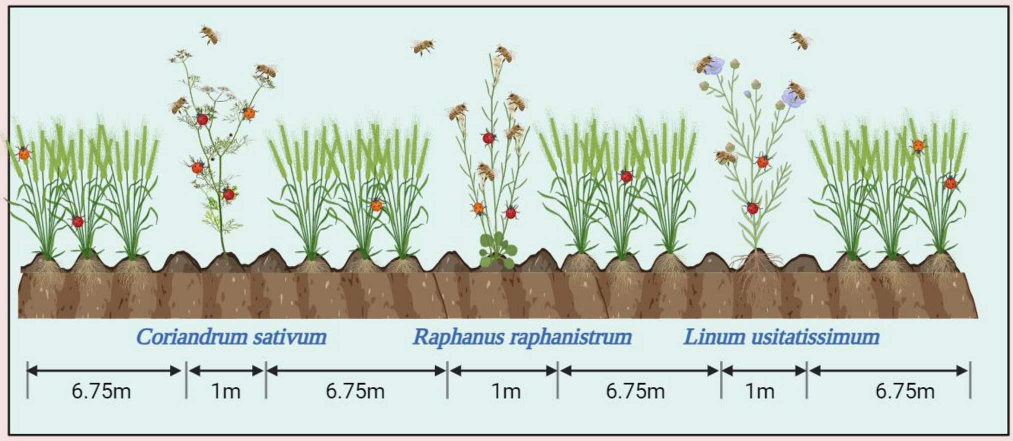
Graphical Abstract



Predator: Coriander (*Coriandrum sativum*) > Singra (*Raphanus raphanistrum*) > Linseed (*Linum usitatissimum*)
Pollinators: Singra (*Raphanus raphanistrum*) > Linseed (*Linum usitatissimum*)> Coriander (*Coriandrum sativum*)

Highlights

•Flowering strips in wheat main crop enhanced the activity and abundance of predators and pollinators.

•Pollinator populations correlated with the timing of blossoming of strip crops.

•Flowering strips enhanced the pest-predator ratio to 5:1 compared with 10:1 in the sole wheat crop.

•Selected flowering strips may benefit conservation efforts by increasing beneficial insect populations.

Abstract: Plant inflorescence is not only the source of nectar and pollen to attract beneficial arthropods but also acts as the major tool for conservation of biodiversity in an agro-ecosystem. The present study aimed to quantify the ecosystem service value of arthropod predators and pollinators through enhanced plant biodiversity and mass flowering. The experiment consisted of a direct comparison between wheat monoculture crop versus wheat crop embedded with one strip each of three floral crops [singhra (*Raphanus raphanistrum* L.), coriander (*Coriandrum sativum* L.) and linseed (*Linum usitatissimum* L.)]. Thirty beneficial insect species including pollinators and predators belonging to 14 families from six arthropod orders were recorded in the strip planted field. Dominant pollinators' activity increased linearly with the blooming of *R. raphanistrum*, *L. usitatissimum* and *C. sativum*, while predator populations were directly proportional to aphid populations. The maximum foraging activity of dominant pollinators was recorded during afternoon hours (1200hr) than in the morning and evening hours. Flower initiation, duration of blooming, uniformity of flowering and flower morphometric variation directly affected the population activity of pollinators, where predator occurrences were dependent on the abundance and activity of herbivores, *Rhopalosiphum padi* (bird cherry-oat aphid) and *Sitobion avenae* (grain aphid), on wheat. Both pollinator and predator population dynamics positively correlated with ambient temperature, whereas the relative humidity and rainfall negatively impacted beneficial arthropod activities. Therefore, the selection and appropriate mix of suitable crops as intercrop, border, cover or bunker crops will provide an opportunity for enhanced habitat diversity thereby increasing pollinator and predator activities and lowering the risk of pest-induced yield losses.

Keywords: flowering strips; conservation; predators; pollinators; intercropping; sustainability

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1. Introduction

Wheat (*Triticum aestivum* L.) being the most important cereal crop is cultivated for its excellent food quality worldwide. Globally, wheat production ranks second after rice contributing 35% of total food grain production [1, 2]. Owing to its nutrition and affordable price, wheat is the preferred grain food and is consumed by 35% of the world's population [3]. However, wheat crops are attacked by various herbivorous arthropods under field conditions, causing 20-37% grain yield loss [4]. Over 100 herbivorous arthropods cause damage to the crop at various growth stages and a dozen of them attain major pest status from seedling to maturity of wheat [3]. Of these, the aphids, *Rhopalosiphum maidis* (Fitch), *Rhopalosiphum padi* L., *Sitobion miscanthi* (Takahashi), *Sitobion avenae* (F.), *Schizaphis graminurn* (Rondani), *Metopoliphiurn dirhodum* (Walker) and *Diuraphis noxia* (Mordvilko ex Kurdjumov), are the major pests that attack during the reproductive stage of the crop in northwestern plains of India [5,6]. These aphids can cause yield losses between 20 to 30% through direct feeding [7] or transmitting viral diseases as a vector [8].

Several chemical pesticides are used frequently to control the aphids infesting wheat to maximize the grain yield [9]. However, the indiscriminate use of insecticides directly affects the soil and water quality, threatens the diversity of beneficial natural enemies such as predators, parasitoids and pollinators, contributes to the development of pest resistance, and poses risks to human health and the environment [10,11]. Consequently, the loss of major ecosystem services such as pollination, biological pest control, water and fertility regeneration and nutrient recycling follows [12]. Therefore, a more ecosystem-based pest management approach must be formulated to lower the pest pressure below the economic threshold level while enhancing the ecosystem services [13, 14]. This approach includes habitat manipulation that promotes the restoration of functional agro-biodiversity in the agricultural landscape [15]. This strategy involves conserving beneficial insects by providing them with diverse vegetation, alternative prey, and food resources that enhance fecundity and longevity and withstand adverse environmental conditions for increased performance [16,17,18]. Nevertheless, the recent intensification of agriculture and urbanization has drastically impacted the diversity of predators and bee pollinators [19]. Therefore, it is a pressing need to offer suitable habitats for their conservation in the ecosystem.

Habitat manipulation is a modified concept of cultural methods wherein cultivating crops in a piece of land with high pollen and nectar are available in flowers to facilitate colonization and conservation of beneficial insect fauna, such as predators and pollinators [17,18,20,21]. The use of multi-floral strips in a cultivated field to enhance plant diversity has increased the activity of beneficial arthropod diversity and biological pest control in the agro-ecosystem [22,23]. The success of this strategy largely depends on several factors such as flowering time, synchronization of beneficial insect fauna and pests, nectar and pollen production [15, 24,25], and flower shape and colour [26,27] and should be explored for an effective implementation of this strategy. These factors affect the reproductive fitness of beneficial arthropods like pollinators and predators in the ecosystem [17,28] which, in turn, would render the effectiveness of the beneficial arthropods. Therefore, habitat management is a potential area that needs to be explored to create a more favourable environment for locally occurring beneficial arthropods and as an alternative or complementary option for chemical control [29,30]. Thus, the present study aimed to determine whether the activity of aphidophagous predators and diverse pollinators enhanced in a wheat cropping system through incorporating insectary crops. Specific objectives of the study were to quantify i) the effect of flowering period and flower color on the activity of predators and pollinators, ii) the level of predator colonization and enhancement in intercropped system, and iii) the value of intercropping pattern in promoting biodiversity restoration.

2. Materials and Methods

All the growth stages of wheat were closely inspected and the presence and abundance of pests as well as pollinators and predators infesting in sole wheat crop were recorded. The arthropod pests, pollinators, and predators were also counted and recorded for their presence and abundance in the singhra (*R. raphanistrum*), coriander (*C. sativum*) and linseed (*L. usitatissimum*) strips intercropped within the wheat field as well as on sole wheat crop. The collection began in the last week of January, approximately four weeks after sowing each crop to the end of March. The insects visited different flowering crops grown as an intercrop between wheat and were observed and collected twice per week. The abundance of the insect pollinators and predators was recorded during morning, afternoon and evening hours for five minutes each on the randomly selected three plants in an area of 1 × 1 m^2 in the intercropped flower strips as well as from wheat. In addition, the aphid population was also counted from five randomly selected plants from both treatments. The collected arthropods were categorized by insect orders including Hymenoptera, Diptera, Lepidoptera, Coleoptera, and Hemiptera. These collected pollinators, predators and pests were preserved in 70% alcohol for further study. The identity of insect species was confirmed by various insect taxonomists and using the available literature. Weather data including temperature, relative humidity, and rainfall were also recorded during the cropping season from the meteorological observatory located at Department of Agronomy, Agriculture Research Farm, School of Agriculture, LPU, Phagwara, Punjab.

Morphological Variation in Strip Flowers

Floral traits of linseed, singhra and coriander were examined by picking ten flowers for each flowering plant grown in the floral strips. Floral traits such as corolla length, diameter of flower petals, and the number of flowers per plant were recorded in the morphometric study [31]. Pollen characteristics of each flower were also observed for their shape and size under the microscope.

Statistical Analysis

All the analyses were performed using SPSS (22 version). The student t-test was used to compare the population of predators and pollinators observed in the flowering strips. Pearson's correlation was performed to estimate the effect of weather parameters on the population of aphids, predators and pollinators that occurred in wheat as well as in the floral strip. The data obtained on the morphometrics including flower densities, corolla length and flower size of floral plants were subjected to descriptive analysis.

3. Results

3.1. Collection of Beneficial Arthropods in Floral Strips

A total of 30 beneficial insect species including pollinators and predators belonging to 13 families of the six insect orders were recorded (Table 1). In floral strips, 25 species of pollinators and five species of predators were recorded. Pollinators visiting floral strips belonged to orders Hymenoptera, Diptera, Lepidoptera and Hemiptera. In Hymenoptera, the bee species *Apis mellifera* L., *Apis cerana* F., *Apis florea* F., and *Apis dorsata* F. were abundant and occurred frequently. Seven Syrphidae species namely, *Ceriana* sp., *Eristalis tenax* L., *Eristalinus tabanoides* Jaenicke, *Eristalinus obscuritarsus* Meijere, Ep*isyrphus balteatus* De Geer,*Eupeodus bucculatus* and *Metasyrphus corolla* F. were recorded as dipteran pollinators (Table 1). Five species of aphidophagous coccinellids in the order Coleoptera were recorded preying on aphids *Rhopalosiphum padi* (L.) and *Sitobion avenae* (F.) in wheat. However, *Coccinella septempunctata* and *Cheilomenes sexmaculata* were observed with high intensity in both the sole wheat and intercropped wheat (Table 1).

3.2. Effect of Floral Strips on Predators and Pollinators

Predator densities were considerably higher in singhra (df= 24, t=2.603; p=0.016), whereas significantly lower numbers were recorded in coriander (df=24, t=3.177; p=0.004) compared to that in linseed (Figure 1). At the same time, densities of pollinators did not significantly vary between singhra and linseed where bluish colour flowers with oval and spherical pollen, respectively, appeared more preferred as indicated by greater abundance. However, white colour flower with rod shape pollen in coriander were significantly less preferred by pollinators compared to that on linseed (df=17, t=2.244; p=0.038) and singhra (P>0.05) (Figure 1). The activity of pollinators was greater during noon hours (1200hr) as compared to morning (0900hr) and evening (1700 hr) hours on the floral strips (Figure 2). The most common pollinator taxa found on floral strips were Apidae, Syrphidae and Pieridae and predator Coccinellidae (Table 1). The combination of purple and white flowers of singhra bloomed for 49 days and attracted 2895 pollinators followed by coriander (1324 individuals) with asymmetrical white flowers. The fewest numbers of pollinators were attracted to linseed (1185 individuals) having bluish flowers with oval and spherical pollen. Similarly, higher densities of predators were obtained on coriander (704 individuals) with blooming period of 33 days and lowest densities observed in linseed (310 individuals) where flowers bloomed for up to 28 days (Table 2).

3.3. Population Dynamics of Predators and Pollinators on Floral Strips

The population density of beneficial insects gradually increased with flower blooming time and significantly varied between the floral strips (Figure 3). The activity of beneficial insects in *R. raphanistrum* strip was observed between 3rd standard meteorological week (SMW) to 10th SMW, with peak activity during 8th SMW (4.21/m^2 of Apidae, 5.18/m^2 of Syrphidae and 1.18 / m^2 of Pieridae) coinciding with flower blooming period (Figure 3a). The Coccinellidae population peaked at 8th SMW synchronizing with the aphid population (Figure3a). However, the peak activity of pollinators was recorded during 9th SMW (2.36 /m^2 of Apidae and 4,68/ m^2 of Syrphidae) during full blooming of crops and coccinellids reached at 12th SMW (0.58/ m^2) (Figure 3b). The activity of beneficial insects in coriander began with the initiation of blooming at 8th SMW and continued till crop maturity (13th SMW) with the peak density occurring at 11th SMW (Figure 3c).

3.4. Impact of Abiotic Factors on Predators and Pollinators

Temperature influenced the predator and pollinator densities in the floral strips with a strong positive correlation between temperature and arthropod densities, whereas relative humidity and rainfall correlated negatively with beneficial arthropod densities on flower strips. In coriander strip, the predator density positively correlated with both maximum (r = 0.72) and minimum (r = 0.89) temperature and the predator density improved with increase in temperature. The minimum temperature also correlated positively with pollinator densities in coriander strip. Aphid population on wheat was negatively impacted by rainfall (r = -0.83) and relative humidity (Table 3).

3.5. Interaction of Pest and Predator in Relation to Crop Growth Stages

The wheat crop reached the milk stage at 7th SMW which coincided with the occurrence of aphid population on both strip-cropped and sole wheat plots. Aphid population gradually increased from 7th SMW up to 11th SMW and then declined during 13th SMW where the crop attained the dough stage (Figure 4). Aphid densities varied between 67.8-125.3 and 85.8- 212.2 aphids per five plants in wheat with intercropped flowering strips and sole wheat crop, respectively. The average population of aphid was significantly lower in intercropped wheat than in sole wheat crop (df= 10, t=-2.262; p=0.047), (Figure 4). As expected, predator population was significantly greater in wheat with strip-cropping of singhra, linseed and coriander compared with that in the sole wheat crop (df= 10, t=2.395; p <0.005). The likely scenario for this predator enhancement in strip-cropped wheat is the abundance of flower nectar and pollen supporting predator development together with sufficient availability of aphid population (Figure 4). Numerically, the highest average predator population (22.20 ±6.57) and lowest aphid population (103.17 ±18.99) were observed in flowering strip incorporated field compared to that in sole wheat crop where predator actively suppressed the aphid population. It was also revealed that the pest and defender (predator) ratio (P:D ratio) was 5:1 in strip-cropped plots while the ratio was 10:1 in sole-planted wheat plots.

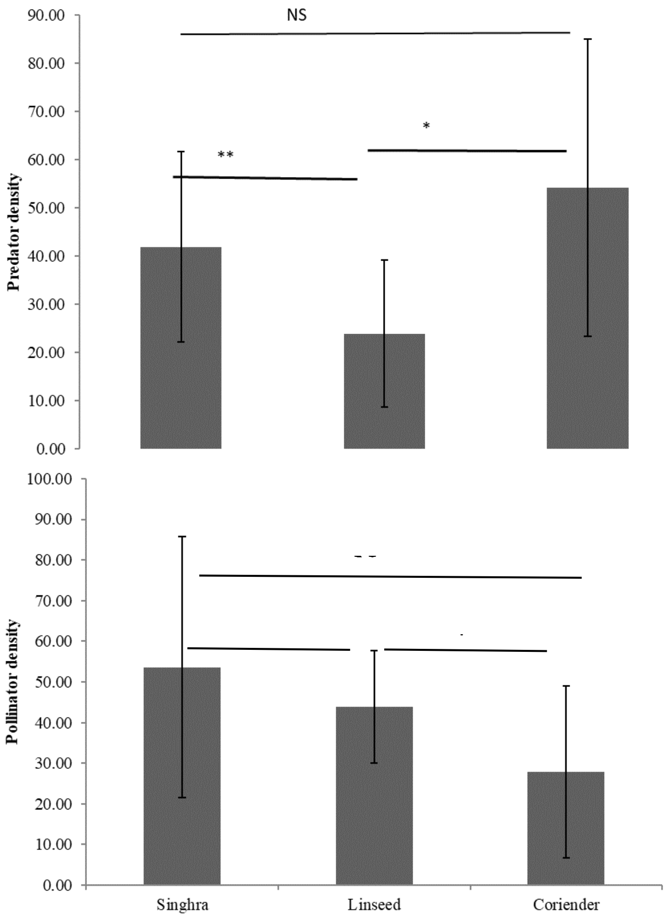

Figure 1. Comparison of predators and pollinators within flowering strips.

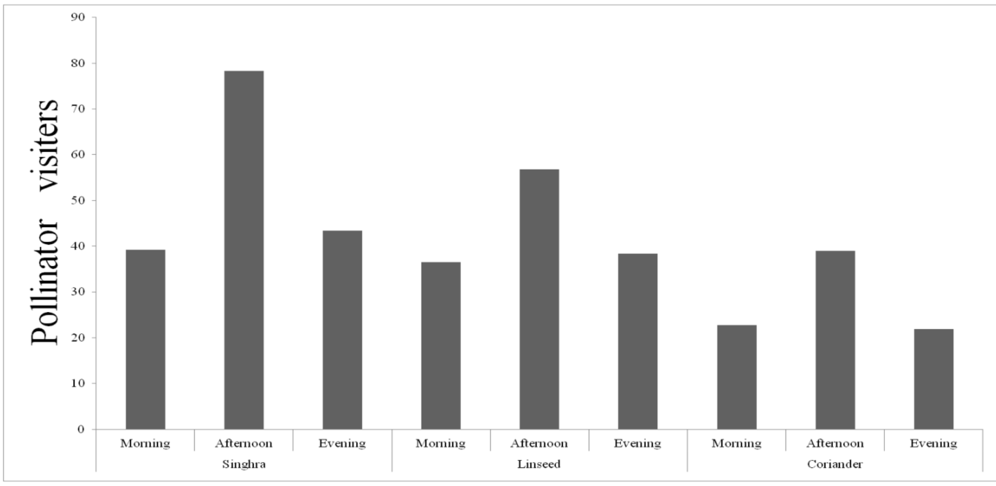

Figure 2. Temporal patterns of diurnal pollinator activity on flowering strips.

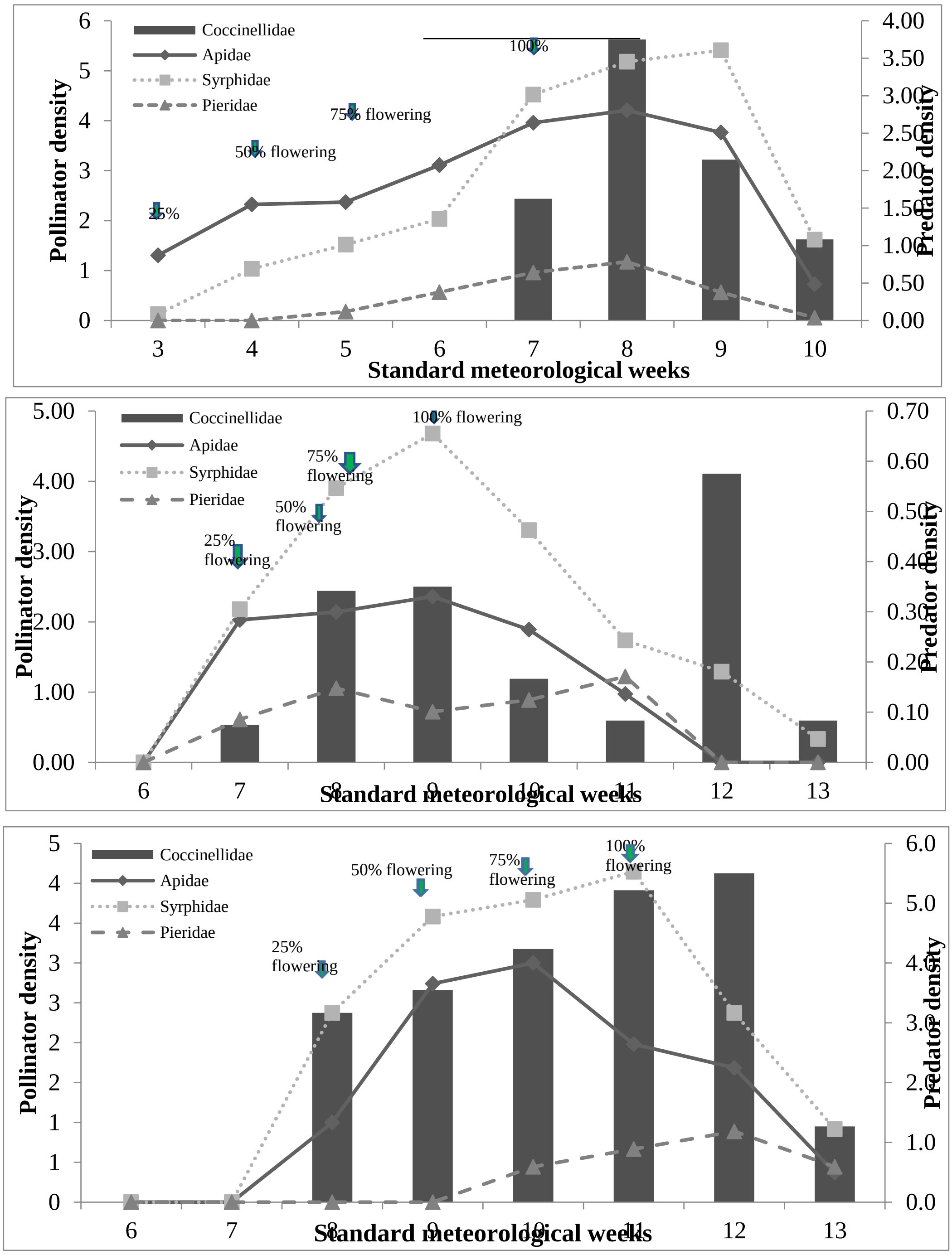

Figure 3. Populating fluctuation of predators and pollinators in floral strips.

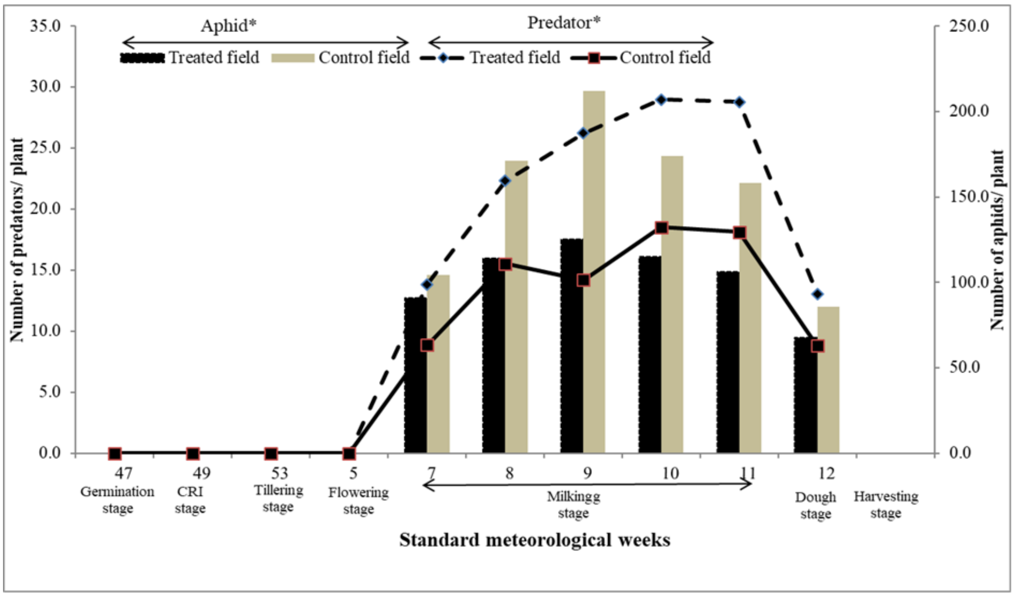

Figure 4. Pest predator relations with critical growth stage of wheat crop.

Table 1. Beneficial arthropod visitors in intercropped with floral strips.

Common name	Scientific name	Intensity	Family	Order	Type
Western honey bee	*Apis mellifera* Linnaeus	High	Apidae	Hymenoptera	Pollinators
Indian bee	*Apis cerana* Fabricius	High	Apidae	Hymenoptera	Pollinators
Little honey bee	*Apis florae* Fabricius	Medium	Apidae	Hymenoptera	Pollinators
Rock bee	*Apis dorsata* Fabricius	Medium	Apidae	Hymenoptera	Pollinators
Carpenter bee	*Xylocopa* sp.	Medium	Apidae	Hymenoptera	Pollinators
Sweet bee	*Halictus* sp.1	Low	Halictidae	Hymenoptera	Pollinators
Sweet bee	*Halictus*sp.2	Low	Halictidae	Hymenoptera	Pollinators
Hover fly	*Ceriana* sp.	Low	Syrphidae	Diptera	Pollinators
Drone fly	*Eristalistenax Linnaeus*	Medium	Syrphidae	Diptera	Pollinators
Hover fly	*Eristalinustabanoides*(Jaenicke)	Low	Syrphidae	Diptera	Pollinators/ predator
Lagoon Flies	*Eristalinusobscuritarsus*(Meijere)	Medium	Syrphidae	Diptera	Pollinators
Marmalade hoverfly	*Episyrphusbalteatus*(De geer)	High	Syrphidae	Diptera	Pollinators
Hoverfly	*Eupeodes* sp.	High	Syrphidae	Diptera	Pollinators/ predator
European hoverfly	*Metasyrphus corolla* (Fabricius)	Medium	Syrphidae	Diptera	Pollinators
Snout fly	*Stomorhina*sp.	Low	Rhiniidae	Diptera	Pollinators
Housefly	*Musca* sp.	Low	Muscidae	Diptera	Pollinators
Plain tiger	*Danauschrysippus*	Medium	Nymphalidae	Lepidoptera	Pollinators
Painted lady	*Venessacardui*(Linnaeus)	Low	Nymphalidae	Lepidoptera	Pollinators
Cabbage butterfly	*Pieris brassicae*	High	Pieridae	Lepidoptera	Pollinators
African clouded yellow	*Coliaselecto*(Linnaeus)	Low	Pieridae	Lepidoptera	Pollinators
Howk moth	*Macroglossumstellatarum*	Low	Sphingidae	Lepidoptera	Pollinators
Seed bug	*Graptostethusservus*(Fabricius)	Low	Lygaeidae	Hemiptera	Pollinators

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Shield bug	*Dolycoris indicus* Stal.	Low	Pentatomidae	Hemiptera	Pollinators
Lychee Shield bug	*Chrysocorispatricius* (Fabricius)	Medium	Scutelleridae	Hemiptera	Pollinators
Red pumpkin beetal	*Raphidopalpafoveicollis*	Low	Chrysomelidae	Coleoptera	Pollinators
Seven spotted ladybird beetle	*Coccinella septempunctata* Linnaeus	High	Coccinellidae	Coleoptera	Predator
Six-spotted zigzag ladybird	*Cheilomenes sexmaculata* (Fabricius)	High	Coccinellidae	Coleoptera	Predator
Transverse ladybird	*Coccinella transversalis* (Fabricius)	Medium	Coccinellidae	Coleoptera	Predator
Spotted amber ladybeetle	*Hippodamiavariegata*(Goeze) sp.1	Low	Coccinellidae	Coleoptera	Predator
Harmonia ladybeetle	*Harmonia dimidiate* (Fabricius)	Medium	Coccinellidae	Coleoptera	Predator

Table 2. Morphometric variation of flowering strips.

Crop name	Flower type	Pollination type	Flower colour	Flowers per plant				Total flowers (Number)	Diameter of flower (cm)	Ovary length (cm)	Type of pollen	Blooming period (days)	Total pollinators (Number)	Total Predators (Number)
				25% flowering	50% flowering	75% flowering	100% flowering							
Singhra	Cross Shaped	Cross	Purple and white combination	14 ± 3#	24 ± 4	38 ± 8	48 ± 8	124	3.2 ± 0.19	1.6	Oval	49	2895	544
Linseed	Disk Shape	Cross	Blue	6 ± 1	8 ± 1	8 ± 1	9 ± 1	32	2.4±0.16	0.8	Spherical	28	1185	310
Coriander	Asymmetrical	Cross	White	9 ± 1	14 ± 3	22 ± 2	31 ± 2	76	1.2 ± 0.11	0.2	Rod	33	836	704

#value represent as ±SD (standard deviation) from randomly selected ten plants .

Table 3. Effect of environmental factors on predator and pollinators population in inter.cropped field.

Factors	Aphid population	Pollinator population			Predator population		
		Singhra	Linseed	Coriander	Singhra	Linseed	Coriander
Maximum Temp (0C)	0.279	0.570	0.134	0.644	0.395	0.152	0.721*
Minimum Temp (0C)	0.392	0.356	0.516	0.943**	0.187	0.162	0.889**
Maximum RH (%)	-0.049	-0.020	0.168	-0.498	-0.008	0.085	-0.618
Minimum RH (%)	-0.010	0.045	0.265	-0.499	0.236	0.131	-0.621
Rainfall (mm)	-0.834*	--	-0.467	0.138	--	0.125	0.381

*Correlation is significant at the 0.05 level (2-tailed).**. Correlation is significant at the 0.01 level (2-tailed).

4. Discussion

4.1. Collection of Beneficial Arthropods in Floral Strips

The use of floral strips in cultivated crops has been gaining importance in conservation biological control strategies by enhancing the diversity of beneficial arthropods [15, 18]. This type of habitat manipulation helps to conserve beneficial insect fauna and provide benefits if adopted after multiple years of field testing [15,22, 32,33]. In this study, the deployment of floral strips enhanced the diversity and abundance of beneficial arthropods in wheat. It has been found that the activity of beneficial insects such as predators and pollinators was higher in the vicinity of floral strips compared to the sole wheat crop. The higher population of predators and pollinators in strip-cropped wheat can be attributed to the high mobility towards floral strips due to ample availability of pollen and nectar of flowering plants and move to adjacent wheat due to their proximity (predators) as well as for aphid prey on wheat ([34,35,36]. In this study, we recorded 30 species of beneficial arthropods, of which predators and pollinators were the major arthropod groups found on floral strips. Furthermore, higher densities of Apidae, Coccinellidae, Syrphidae and Pieridae were observed in all three floral strips examined in our study. These findings are in agreement with earlier studies where predator and pollinator populations were augmented in the presence of floral strips [35, 37,38,39]. It is well-known that the increase in landscape heterogeneity in agricultural land promotes predators and pollinators [28,33, 36]. In this study, floral strips attracted and enhanced various species of bees, seven species of syrphids and five species of aphidophagous coccinellids. Previous studies have also reported augmentation of bees, coccinellids and syrphids on the landscape planted with flowering plants [15, 37,40].

4.2. Effect of Floral Strip on Predators and Pollinators

Floral recourses like nectar and pollen can be a significant source of protein and sucrose for pollinators and predators for successive reproduction [41, 42]. A synchronized sowing time of insectary crops, density and type of crops (nectar and pollen source) and floral diversity are important factors to enhance predator and parasitoid activity in an agro-ecosystem [43,44,45,46,47]. Along with a phenotypic character like inflorescence height and display size, flower colour was partly responsible for attraction of pollinators and predators [42,48]. In this study, we found that the foraging activities of pollinators like Syrphidae and Apidae in floral strips (singhra and coriander) were more pronounced during afternoon hours because of the intensity of daylight such that the flower petals clusters help to recognize pollinators. Similar results were reported by previous researchers in that a predominant pollinator A. melifera foraging activity peaked after 1200 hours on Brassica napus [49,50,51]. However, the insect visitor's activity after 1100 hours was reduced in linseed as most petals were shed by noon and thereafter insect visitors were not able to get support of petals during foraging [52].

Foraging activity of prominent pollinators depends on the duration of blooming period. Our work demonstrated that the maximum mass flowering period of up to 49 days in singhra was directly proportional to pollinator and predator activities compared to that in coriander and linseed. Floral traits of coriander plants were more attractive for several natural enemies like syrphids, contributing to a successful strategy of predator conservation [53,54,55,56]. Morphometric variations in plants influenced the density and activity of beneficial arthropods. Experts in the field suggest that the flower with a short corolla facilitates the access to nectar and pollen, whereas white flowers stimulated feeding in hoverflies [26, 53, 57]. Therefore, the flower strip and landscape characteristics are significant and integral components of an agroecosytem that contribute to the enhancement of ecological services and the promotion of conservation programs [58,59].

4.3. Population Dynamics of Predators and Pollinators on Floral Strips

The presence of flowers that contain nectar and pollen is a variable that influences the behavior of pollinators. This study showed that the populations of pollinators including bee and non-bee species were directly correlated with blooming time of flowers. These findings are consistent with [60] who stated that the abundance of pollinators attracted at full blooming period increased the quality and quantity of seed yield in mustard and radish [61]. The floral scent can be a significant factor for successful pollinators where the actual number of visits significantly decreased or increased over time [62]. Therefore, pollinator visits were highly impacted by chemical properties of nectar, quantity of pollen grains and floral canopy in crops [63].

Predators are important biocontrol agents for suppressing the soft-body pest insects. Our study clearly demonstrated the synchronization of predator-prey population dynamics in both monoculture wheat and intercropped wheat, except that the intercropped wheat attracted significantly greater densities. In several other studies, primary predators such as coccinellids and syrphids increased when wheat was intercropped with Brassica and pulse crops [64,65,66,67]. The increase in predator abundance in intercropped system is attributed to both the early colonization of prey due to habitat heterogeneity and availability of sufficient amount of pollen and nectar to support predators even when the prey population is insignificant [69]. As with singhra and linseed, the coriander supported a large diversity of coccinellids. It is possible that these coccinellids migrate from the wheat crop to coriander to oviposit and pupate. Also, the volatile substance released from the coriander crop may be partly responsible for increased attraction of the adult aphidophagous Coccinellidae [70]. Furthermore, the consumption of pollen may have been a contributing factor in the diversification of Coccinellidae family of predators [71].

5. Conclusions

Our results support that the existing landscape composite can be modified to diversify the agroecosystem to manage soft-bodied insect in wheat via planting of flower strips of *R. raphanistrum, C. sativum* and *L. usitatissimum*. The flower strips provided nectar and pollen in direct proximity to the predator and pollinator. Aside from pollen and nectar, additional elements such as flower color, blooming period, and weather parameters all played significant influence on pollinator and predator colonization and aggregation. Therefore, we emphasize the need for additional research into the interaction between predator/pollinators and flowering strips to further characterize habitat heterogeneity and conservation biological control across various cropping systems.

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Data Availability Statement: Data is contained within the article in the form of tables and figures.

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Conflicts of Interest: The authors declare no conflicts of interest.

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