Artículos

Effect of associated floral diversity on spatial-temporal abundance of aphids and coccinellids in wheat crops

Efecto de la diversidad floral asociada en la abundancia espacio-temporal de pulgones y coccinélidos en cultivos de trigo

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Abstract: Wheat crops are affected by aphids (Aphididae) that can be controlled by coccinellids (Coccinellidae). A spatial-temporal dynamics study of aphids and coccinellids in wheat was carried out during the crop cycle at different distances from Associated floral diversity (AFD). Four transects (repetitions) were established and it was fortnightly monitored with sweep net at six distances from AFD (5, 10, 20, 40, 80, and 160 m). Species were identified with a stereoscopic microscope. Aphid distribution pattern differed according to phenological stages: Disperser (tillering and stem elongation), Cultural (booting and anthesis, with maximum densities at 160 m) and Ubiquist (milk and dough grain). Three coccinellids were mostly recorded, *Eriopis connexa* (Germar), *Harmonia axyridis* (Pallas) and *Cycloneda ancoralis* (Germar) which abundance differed according to the site. *H. axyridis* (76,9 %) prevaled in DFA and *E. connexa* (71 %) in wheat, with Ecotone and Cultural patterns, respectively. Coccinellid abundance reached its maximum in milk grain with an 82 % reduction of aphid population. The spatial-temporal variability of aphids and coccinellids documented during the crop cycle emphasizes the importance of monitoring areas far from the edge and studying the coccinellid winter ecology for its conservation and its synchronization with aphids.
Keywords: Biological control, Field borders, Ladybird, Predators.
Resumen: El trigo es afectado por pulgones (Aphididae) que pueden ser regulados por coccinélidos (Coccinellidae). Se analizó la dinámica espacio-temporal de pulgones y coccinélidos según las etapas fenológicas del trigo y distancia a la diversidad floral asociada (DFA). Se establecieron cuatro transectas (repeticiones) y se monitoreó quincenalmente con red de arrastre a seis distancias de la DFA (5, 10, 20, 40, 80, y 160 m). Las especies se identificaron con microscopio estereoscópico. El patrón de distribución de pulgones varió según las etapas fenológicas: Dispersor (macollaje y elongación de tallo), Cultural (encañazón y antesis, con máximas densidades a 160 m) y Ubicuo (grano lechoso y pastoso). Se registraron principalmente tres coccinélidos: *Eriopis connexa* (Germar), *Harmonia axyridis* (Pallas) y *Cycloneda ancoralis* (Germar). La especie más abundante varió según el sitio: *H. axyridis* (76,9 %) en la DFA y *E. connexa* (71 %) en trigo, con patrones de Ecotono y Cultural, respectivamente. La abundancia de coccinélidos alcanzó su máximo en grano lechoso, coincidiendo con una reducción cercana al 82 % en la de

pulgones. Dada la variabilidad espacio-temporal de pulgones y coccinélidos en trigo, es importante incluir zonas alejadas del borde en los monitoreos y estudiar la ecología invernal estos últimos para su conservación y sincronización con los pulgones.

Palabras clave: Bordes de campo, Control biológico, Mariquitas, Predadores.

INTRODUCTION

Aphids (Hemiptera, Sternorrhyncha) are among the most important pests in wheat crops worldwide, as they are found in all temperate regions and cropping systems and have the potential to reduce yields (Sadras et al., 1999, Poehling et al., 2017). The economic impact of aphids on wheat varies according to species, abundance, and site of attack (Poehling et al., 2017). Firstly, aphids feed on the phloem system, extracting necessary nutrients for plant growth and reproduction (Dedryver et al., 2010), thus reducing the transport of photosynthates to the grains (Poehling et al., 2017). Secondly, some species inject phytotoxic saliva during feeding, that can induce morphological and biochemical disturbances (Sadras et al., 1999; Dedryver et al., 2010; Poehling et al., 2017). Thirdly, aphids transmit numerous viruses (Dedryver et al., 2010, Poehling et al., 2017), being Barley Yellow Dwarf Virus (BYDV) one of the most widespread and harmful in this crop (Poehling et al., 2017). Finally, they excrete honeydew that blocks stomata and promotes the growth of saprophytic fungi, thereby reducing the photosynthetic efficiency (Sadras et al., 1999, Dedryver et al., 2010, Poehling et al., 2017). Consequently, these impacts result in losses in both yield and grain quality (Sadras et al., 1999). In Argentine cereal crops, the principal aphid species recorded are *Schizaphis graminum* (Rondani), *Metopolophium dirhodum* (Walker), *Sitobion avenae* (Fabricius), *Rhopalosiphum padi* (L.), and *Diuraphis noxia* Kurdjumov (Carmona et al., 2017). These aphids can be regulated by several groups of natural enemies (Brewer & Elliott, 2004). Among predators, coccinellids adults and larvae (Coleoptera: Coccinellidae) and hoverfly larvae (Diptera: Syrphidae) are the most important (Brewer & Elliott, 2004; Jan et al., 2017).

Associated floral diversity (AFD), defined as native or naturalized vegetation that grows spontaneously near the crop, may affect the spatial and temporal activity of both aphids and their predators. Within AFD, predator adults can feed, seek shelter, and enhance their fitness by supplementing their diet with pollen, nectar, and other floral secretions (Landis et al., 2000). Additionally, AFD can support a variety of aphid species (Zumoffen et al., 2015) and other arthropods, which may serve as alternative prey for predators (Landis et al., 2000). Consequently, areas with AFD act as reservoirs for both predators and aphids that may subsequently migrate to nearby crops. This process known as "Spillover", is defined as the movement of individuals between habitats with different resources and it is an important ecological process influencing trophic dynamics between connected ecological communities (Tscharntke et al., 2005; Blitzer et al., 2012). The increased activity of biological control agents in AFD is linked to enhanced pest control services in crops (Landis et al., 2000; Albrecht et al., 2020). However, an exponential decline in these services with distance from the field edge has been reported, potentially leading to higher pest densities as the distance from the edge increases (Albrecht et al., 2020). This decline may be related to the dispersal capacity of biological control agents, as Duelli & Obrist (2003) identified five distribution patterns based on individual movement from AFD into the crop at increasing distances. "Stenotopic" species prefer AFD and are generally absent in crops. In contrast, "Cultural" species prefer crops, with higher abundances at greater distances from AFD. "Ecotone" species colonize crops from AFD and prefer the interphase between these habitats. "Disperser" species are more abundant in AFD, with declining as the distance from AFD increases. Finally, "Ubiquists" species lack habitat preference and are found in both environments (Duelli & Obrist 2003; Tscharntke et al., 2005) (Fig. 1). Although these distribution patterns provide a broad framework for understanding species dynamics, studies addressing the spatial and temporal interactions between aphids and their natural enemies in relation to AFD remain scarce. Given that aphid outbreaks can compromise yield and that natural enemies play an important role in their regulation, elucidating these patterns is crucial for improving biological control strategies. Understanding how AFD influences the spatial and temporal dynamics of aphids and coccinellids can provide valuable tools for designing better pest management strategies in wheat crops. Identifying the distribution patterns and behavior of these natural enemies will help to optimize their conservation and to enhance their effectiveness in biological control. This knowledge can be applied not only to local agricultural systems but also to other temperate agroecosystems, promoting more resilient and sustainable farming practices. In this context, the aim of this study was to assess the seasonal relative abundance of coccinellids and aphids in an AFD and a wheat crop at increasing distances from the AFD. We hypothesize that aphid populations progressively increase with greater distances from the AFD within wheat fields. Similarly, we hypothesize that coccinellid populations in wheat decrease as the distance from the AFD increases.

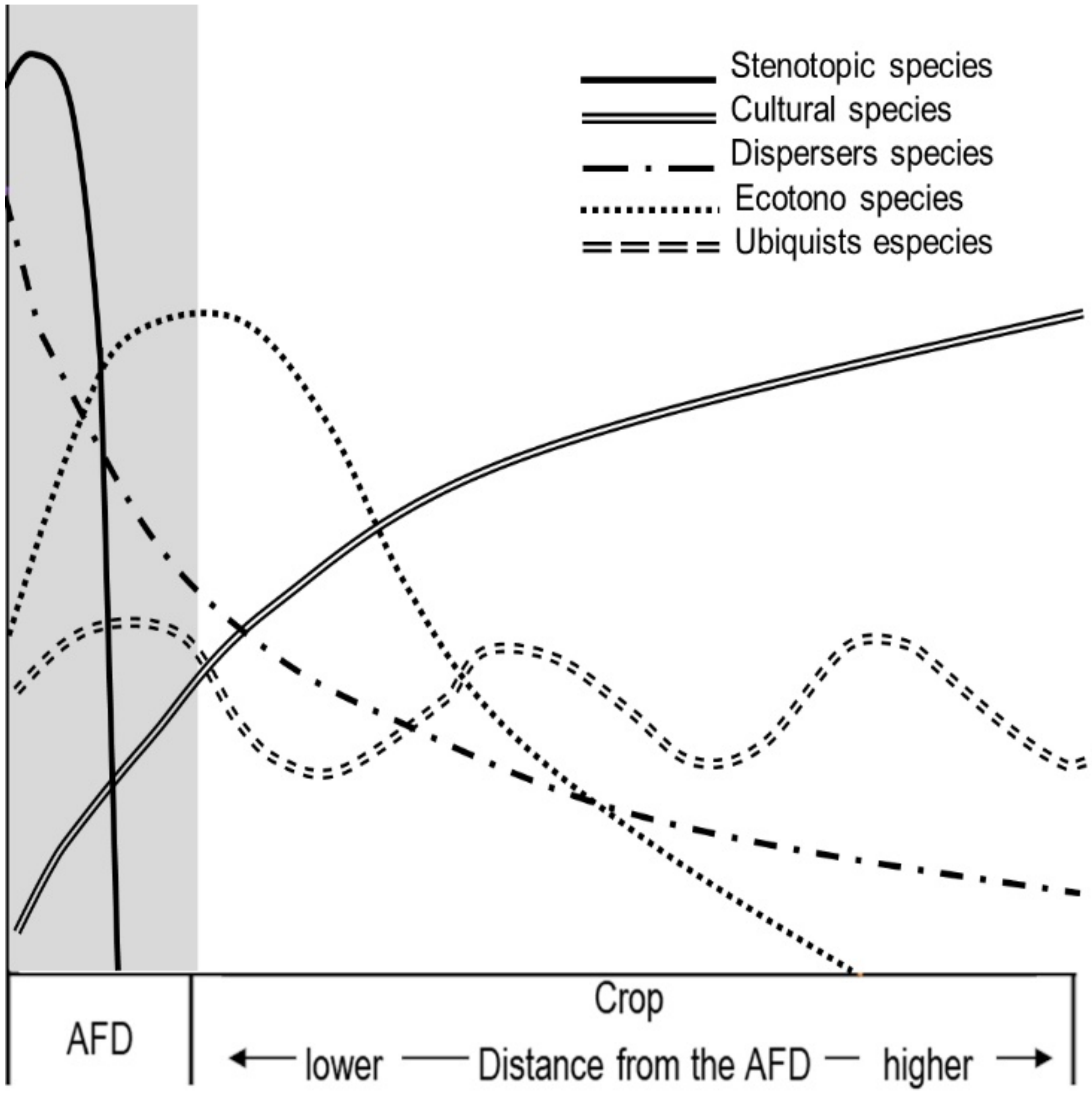

Figure 1.

Distribution patterns from the Associated Floral Diversity (AFD) to the crop, at increasing distances

Adapted from Duelli & Obrist (2003)

MATERIALS AND METHODS

Study Site: The study was carried out from July to December 2019, in a wheat crop (37° 46' 09.85" S, 58° 17' 56" W, and 126 m a.s.l.) with associated floral diversity (AFD) along its northeastern edge (Fig. 2a), located at the Balcarce Integrated Unit (Faculty of Agronomy – Mar del Plata National University and National Institute of Agricultural Technology). Table I details the tree, shrub, and herbaceous species present in the AFD during the study, with

Poaceae being the predominant family. On July 29, an intermediate-short cycle wheat cultivar was sown under no-tillage. No insecticides or herbicides were applied to the whole experimental area. Temperature and precipitation data were obtained from the permanent official weather station at the Balcarce Integrated Unit, situated near the experimental site.

Tree species	
Family	Genus and species
Myrtaceae	*Eucaliptus sp.*
Pinaceae	*Pinus sp.*
Salicaceae	*Populus sp.*
Shrub species	
Family	Genus and species
Rosaceae	*Cotoneaster sp.*
Adoxaceae	*Viburnum lucidum L.*
Asteraceae	*Baccharis tandilensis* (Speg.)
Herbaceous species	
Family	Genus and species
Asteraceae	*Chevreulia sarmentosa* (Pers.)
	Hipochaeris radicata L.
	Carduus acanthoides L.
	Cynara cardunculus L.
	Sonchus oleraceus L.
	Conyza bonaeriensis L.
	Matricaria chamomilla L.
Brassicaceae	*Brassica rapa ssp. Oleifera DC.*
	Raphanus sativus L.
	Cardamine hirsuta L.
Fabaceae	*Medicago sp.*
Poaceae	*Paspalum quadrifarium Lam.*
	Festuca arundinacea Schreb.
	Dactylis glomerata L.
	Phalaris aquatica L.
	Bromus sp.
	Poa sp.
	Agrostis sp.
	Bothriochloa laguroides (DC).

Table I.

Floristic survey from the Associated Floral Diversity (AFD) during October-December 2019.

Sampling: The AFD and the crop were sampled on six dates, with the phenological stage of the crop determined according to Zadoks et al. (1974): October 2 (Z2: Tiller production), October 15 (Z3: Stem elongation), October 31 (Z39: Booting), November 12 (Z6: Anthesis), November 26 (Z7: Grain milk stage), and December 10 (Z8: Grain dough stage). Natural populations of aphids and coccinellids were sampled in the AFD and at increasing distances from the AFD within the crop: 5, 10, 20, 40, 80, and 160 m. Four sampling points were established in the AFD and at each distance in the wheat crop (Fig. 2b). At each sampling point, a sample of 10 sweeps was taken with an entomological sweep net (38 cm diameter x 60 cm depth), moving the net in a full 180-degree perpendicular arc to the transect direction to maintain distance consistency. Samples were placed in bags and kept frozen (-18 °C) in the laboratory at the Balcarce Integrated Unit. Aphid and coccinellid counts were then conducted, with coccinellids identified to species level under a 160x stereoscopic microscope (Olympus) using the taxonomic key of Saini & De Coll (1996).

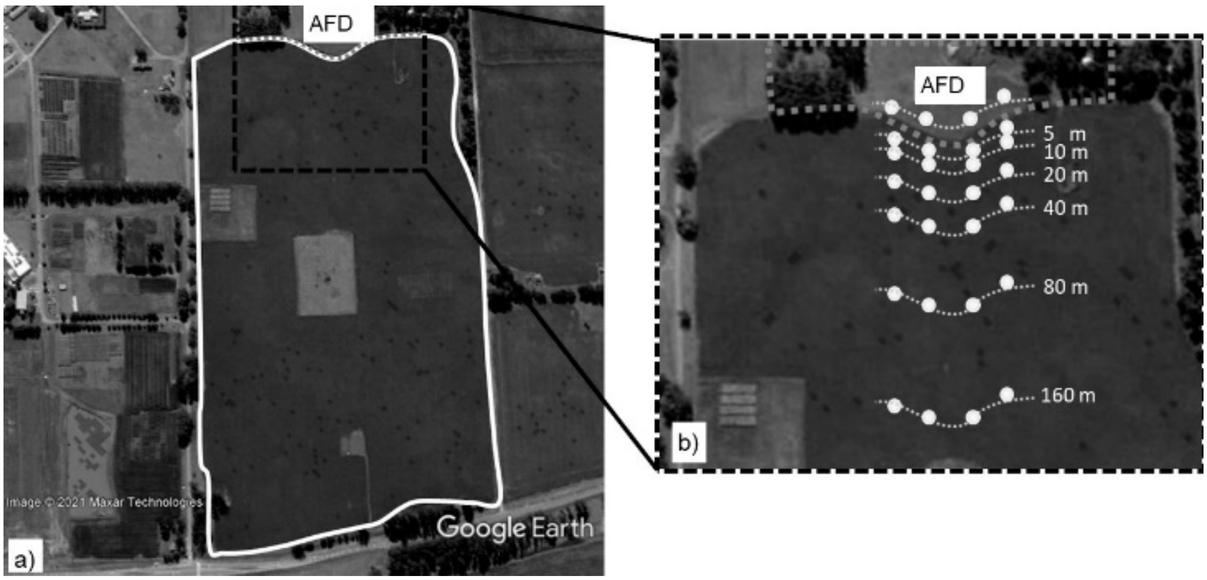

Figure 2.

Geographic location of the study site.

a. The white line delimits the wheat crop, the black dotted line delimits the sampled area, and the grey dotted line delimits the Associated Floral Diversity (AFD). b. Detail of the sampled area, the grey dotted line delimits the AFD and the white dots indicate the four permanent sampling points established for each distance. Therefore, each transect is composed of one dot of each distance. Balcarce Integrated Unit (Faculty of Agronomy- Mar del Plata National University and National Institute of Agricultural Technology). Extracted from Google Earth Pro.

Data Analysis: To compare coccinellid populations in the AFD and the wheat, we calculated species richness, total abundance, and relative abundance. For comparison of aphid and coccinellid populations across the AFD and the wheat crop at increasing distances, the average number of coccinellids (by species, including adults and larvae) and aphids (all species combined) was calculated across the four sampling points. Changes in aphid and coccinellid abundance were analyzed in relation to the wheat crop's phenological stage and distance from the AFD, using repeated measures generalized linear mixed models (GLMM) with a Poisson distribution and log link function. Fixed effects included distance from the AFD, the wheat crop's phenological stage, and their interaction, with sampling point as a random effect. Variance heterogeneity was adjusted for sampling date. When significant effects were observed, pairwise comparisons of adjusted means were made using the Tukey test. All statistical analyses were performed using SAS® On Demand for Academics Version 3.8 (SAS Institute Inc., 2020), with significance set at $p< 0.05$.

RESULTS

Aphid spatial distribution in relation to wheat cycle

From Z2 to Z8, a total of 1,357 and 17,204 aphids were captured in the AFD and in the wheat crop, respectively. Aphid abundance in wheat varied with distance to the AFD ($P < 0.0392$; $F = 2.31$), the phenological stage of wheat ($P < 0.0001$; $F = 245.54$), and there was interaction between both ($P < 0.0001$; $F = 42.28$). Between Z2 and Z3, aphids arrived in wheat (Fig. 3), but their abundance was higher in the AFD (Fig. 4a-b). Then, it increased between Z39 and Z6, recording its maximum abundance in wheat (Fig. 3). At these stages, there was a significant increase in their abundance at increasing distances from the AFD, with the highest value observed at 160 meters. The mean numbers of aphids recorded in the AFD were lower than those reported in the wheat for each of the distances evaluated (Fig. 4c-d). In Z7, a reduction of 82 % in aphid abundance was registered, coinciding with the highest abundance of total coccinellids (Fig. 3) and no clear spatial pattern was observed (Fig. 4e). Finally, at the Z8 stage, aphid abundance continued decreasing, reaching similar values to those recorded in Z2 (Fig. 3). No differences were observed between the AFD and the wheat crop for each of the distances evaluated (Fig. 4f).

Coccinellids in wheat and AFD

No coccinellids were recorded between Z2 and Z3. From Z39 to Z8, a total of 111 and 26 coccinellids were captured in wheat and the AFD, respectively. The taxonomic richness in wheat was five: three species and two genera. The native coccinellid *Eriopis connexa* (Germar) was the most abundant (71 %), followed by the exotic *Harmonia axyridis* (Pallas) (20.7 %) and the native coccinellid *Cycloneda ancoralis* (Germar) (14.4 %). Exceptionally, we found an adult of another species of the genus *Eriopis* Mulsant and some larvae of the native species *Scymnus sp*. In contrast to wheat, the taxonomic richness in the AFD was lower, with only three species. *H. axyridis* was the most abundant (76.9 %), followed by *E. connexa* (15.4 %) and *C. ancoralis* (7.7 %).

Harmonia axyridis was the first species to arrive in the AFD and wheat (Z39), followed by *E. connexa* (Z6) and *C. ancoralis* (Z7) (Fig. 5, Table, III). Coccinellid abundance varied among species both temporally, and spatially. A significant interaction between phenological stage and distance to the AFD was observed for *E. connexa* and *H. axyridis* (Table II). This result indicates that both species exhibited different spatial distributions depending on the phenological stage. On the other hand, spatial distributionof *C.*

ancoralis remained relatively stable, which suggests that it does not exhibit a clear spatial pattern (Table II).

Coccinellid species	PE[a]	Distances (m)	Interaction[b]
Eriopis connexa	P< 0.0001; F= 7.34E32	P< 0.0001; F= 183.71	P< 0.0001; F= 21.20
Harmonia axyridis	P< 0.0001; F= 486.26	P< 0.0001; F= 3.44E35	P< 0.0001; F= 71.69
Cycloneda ancoralis	P< 0.0001; F= 5.93E29	P< 0.0001; F= 1.57E32	P= 0.9052; F= 0.31

[a]Phenological stage of wheat crop
[b]Interaction between PE and Distances (m) from the AFD

Table II.
Statistical analysis of ladybird abundance in Wheat Crop in relation to phenological stage (PE) and distance to Associated Floral Diversity (AFD)

[a]*Phenological stage of wheat crop*
[b]*Interaction between PE and Distances (m) from the AFD*

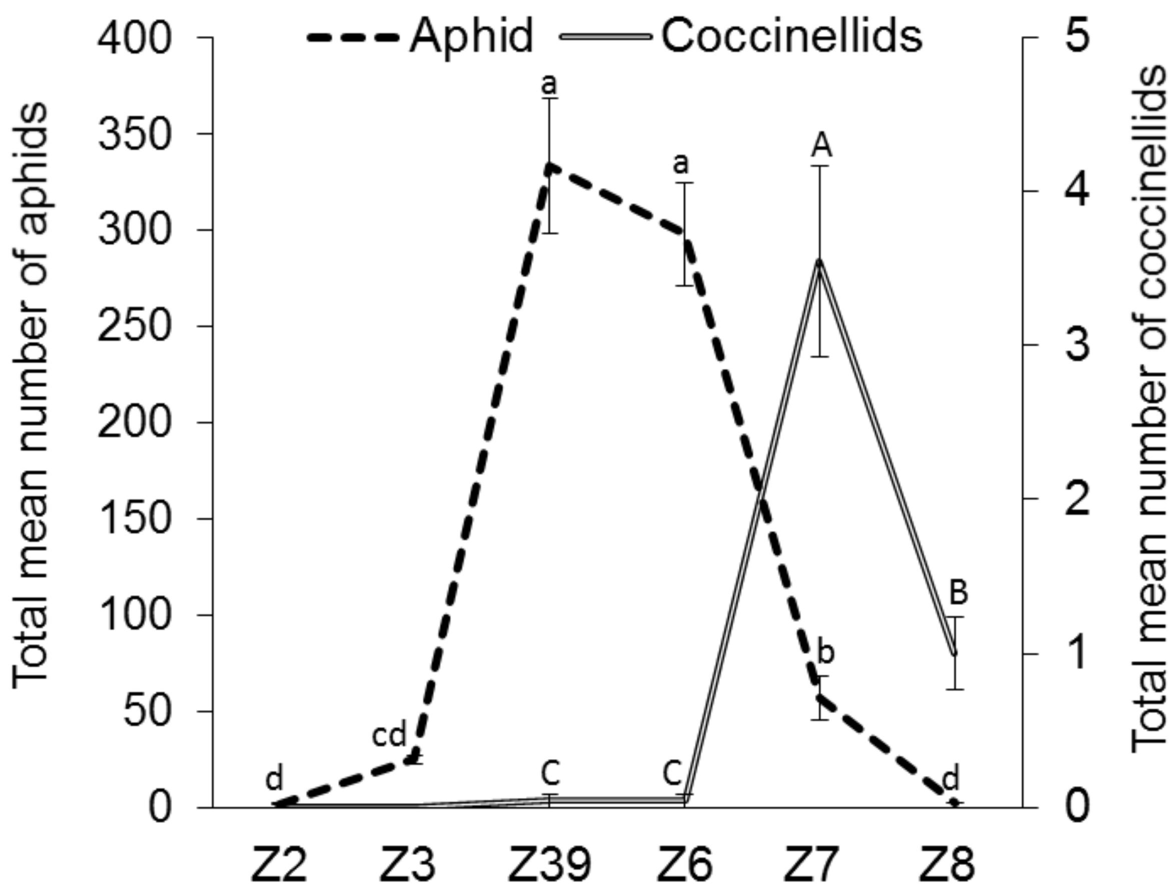

Figure 3.
Mean number of aphids (± standard error) and total mean number of coccinellids (± standard error), in six phenological stages of wheat crop: October 2 (Z2: Tiller production), October 15 (Z3: Stem elongation), October 31 (Z39: Booting), November 12 (Z6: Anthesis), November 26 (Z7: Grain milk stage) and December 10 (Z8: Grain dough stage).
From Z2 to Z8, different lowercase letters indicate significant differences in Mean number of aphids (p< 0.05) and different capital letters indicate significant differences in total mean number of coccinellids (p< 0.05).

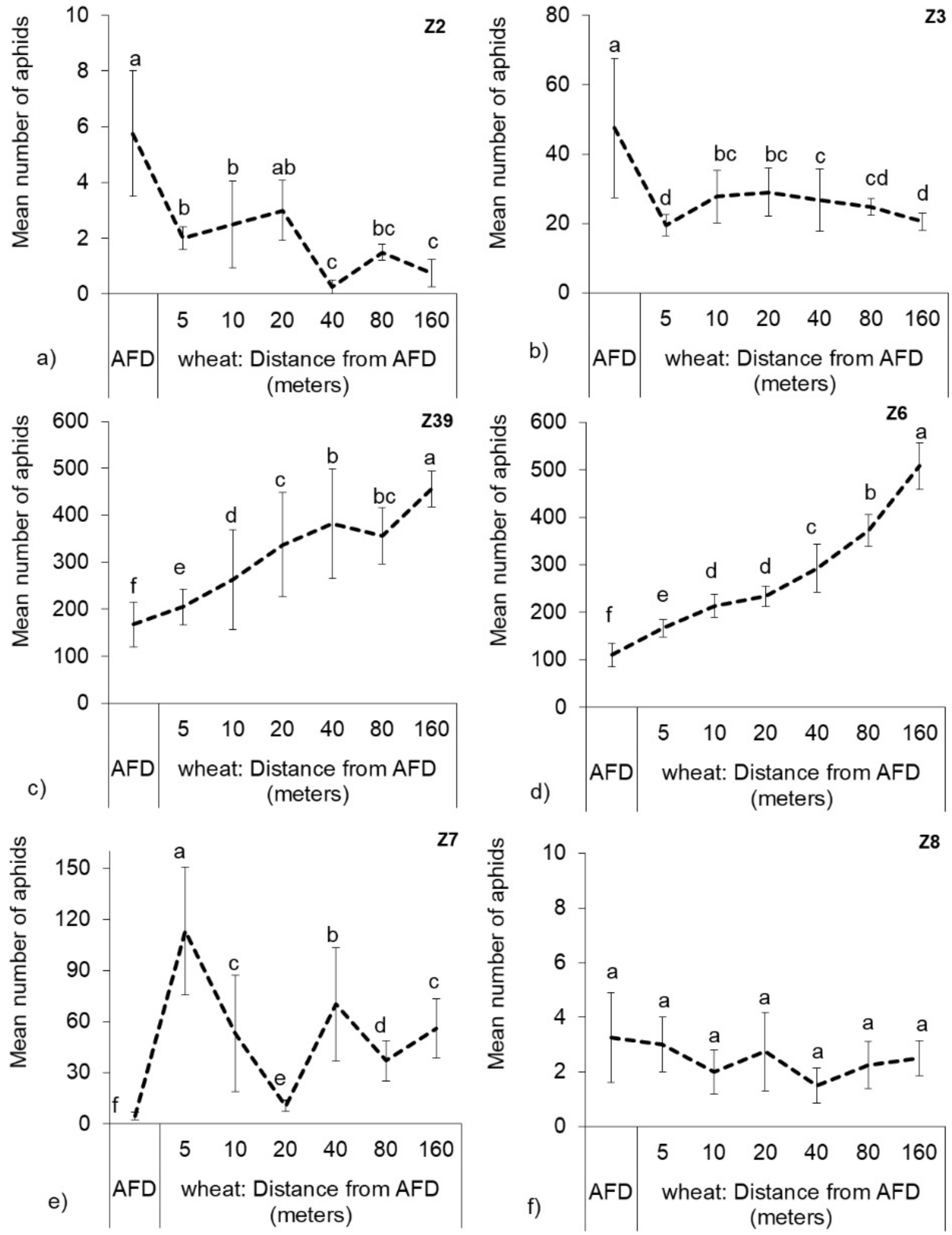

Figure 4.

Mean number of aphids (± standard error) in the Associated Floral Diversity (AFD) and in the wheat crop, at different distances from the AFD in six phenological stages of wheat.

a. October 2 (Z2: Tiller production). b. October 15 (Z3: Stem elongation). c. October 31 (Z39: Booting). d. November 12 (Z6: Anthesis). e. November 26 (Z7: Grain milk stage). f. December 10 (Z8: Grain dough stage). For each phenological stage of wheat crop, different letters indicate significant differences ($p < 0.05$).

Coccinellid spatial distribution in relation to wheat cycle

In Z39, *H. axyridis* was primarily located in the AFD, while its abundance was lower in wheat, where individuals were recorded only at 20 meters from the AFD (Fig. 5a, Table, III). In Z6, its abundance increased in the AFD, although it was not recorded within the crop (Fig. 5b, Table, III). Between Z7 and Z8, its abundance increased in wheat, but only between 5 and 40 meters from the AFD, with no individuals observed at distances further away (Fig. 5c-d, Table, III). As *H. axyridis*, in Z39, *E. connexa* was primarily located in the AFD and recorded its maximum abundance. In wheat, its abundance was lower, with individuals recorded only at 80 meters from the AFD (Fig. 5b, Table, III). Subsequently, it was only found in the crop. In Z7, its density was the highest, with no spatial pattern detected. However, in Z8 the density was lower, increasing with distance from the AFD but without significant differences (Fig. 5c-d, Table, III). *Cycloneda ancoralis* was recorded from Z7. In contrast to the other coccinellid species, it was primarily located in the crop increasing its abundance farther away from the AFD, but not statistically significant (Fig. 5c, Table, III). In Z8, it was only recorded in the AFD, in the areas of the crop close to the AFD (5 meters), and in the areas farther away in the crop (160 m) (Fig. 5d, Table, III).

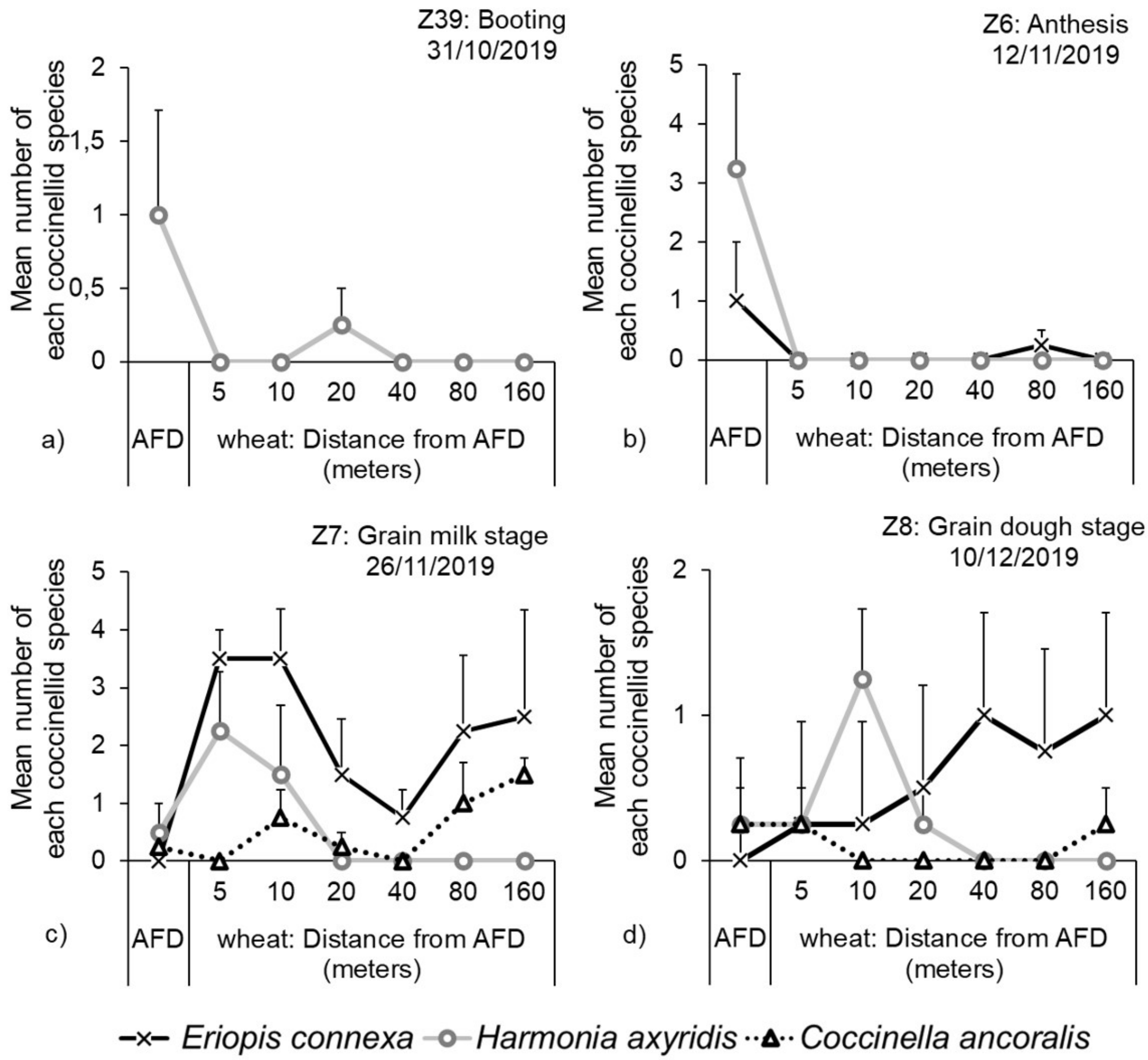

Figure 5.

Mean number of the tree principal Coccinellid species (± standard error) in the Associated Floral Diversity (AFD) and in the wheat crop, at different distances in meters from the AFD in four phenological stages of wheat crop.

a. October 31 (Z39: Booting). b. November 12 (Z6: Anthesis). c. November 26 (Z7: Grain milk stage). d. December 10 (Z8: Grain dough stage).

Coccinellid species	PE	AFD	Wheat: Distance from the AFD (meters)					
			5	10	20	40	80	160
Harmonia axyridis	Z39	1±0,7a*	0	0	0,3±0,3 b	0	0	0
	Z6	3,3±1,6	0	0	0	0	0	0
	Z7	0,5±0,5b	2,3±1 a	1,5±1,2 ab	0	0	0	0
	Z8	0,3±0,3 b	0,3±0,3 b	1,3±0,5a	0,3±0,3 a	0	0	0
Eriopis connexa	Z39	0	0	0	0	0	0	0
	Z6	1±1 a	0	0	0	0,3±0,3 b	0	0
	Z7	0 b	3,5±3,5 a	3,5±3,5 a	1,5±1,5 ab	0,75±0,75 b	2,3±2,3 a	2,5±2,5 a
	Z8	0 b	0,3±0,3 a	0,3±0,3 a	0,5±0,5 ab	1±1 a	0,8±0,8 a	1±1 a
Cycloneda ancoralis	Z39	0	0	0	0	0	0	0
	Z6	0	0	0	0	0	0	0
	Z7	0,3±0,3 b	0	0,8±0,5 ab	0,3±0,3 b	0	1±0,7 ab	1,5±0,3 a
	Z8	0,3±0,3 a	0,3±0,3 a	0	0	0	0	0,3±0,3 a

*Different letters indicate significant differences between the AFD and the different distances from this, for each phenological stage and coccinellid species ($p < 0.05$).
PE:Phenological stage of wheat crop
AFD: Associated Floral Diversity

Table III.

Coccinellid species in the AFD and the crop at different phenological stages and distances.

**Different letters indicate significant differences between the AFD and the different distances from this, for each phenological stage and coccinellid species (p < 0.05).*
PE:Phenological stage of wheat crop
AFD: Associated Floral Diversity

DISCUSSION

Aphid spatial distribution in relation to wheat cycle

The abundance and dispersal pattern of aphids from the AFD to the crop varied with the phenological stage of wheat. The low density of aphids recorded in the early crop stages is desirable, as these stages are more sensitive to aphid damage (Sadras et al., 1999). In that sense, species like *Schizaphis graminum* that could colonize early in the crop, inject strong toxins and virus, damages that could kill the small plants (Dughetti, 2012; Carmona et al., 2017). For this reason, seeds are sometimes treated with systemic insecticides to confer protection during crop emergence (Dughetti, 2012). At that moment, more aphids were recorded in the AFD and their abundance decreased with increasing distance from there. According to Duelli & Obrist (2003), this corresponds to a Dispersal pattern, where AFD acts as a reservoir. On October 8th (between Z2 and Z3), colonies of *M. dirhodum* on *D. glomerata* and other aphid species on *Carduus acanthoides* and *Conyza bonariensis* were observed. This agrees with Zumoffen et al. (2015), who reported that the AFD serves as a reservoir for diverse aphids. According to Duelli & Obrist (2003), species that develop or hibernate in semi-natural areas are only temporarily present in crops, as noted in this study. Consequently, their populations can be maintained over time, independently of the cultivated species.

As aphid abundance increased from Z39 to Z6, more individuals were recorded in the crop at increasing distances from the AFD, indicating a Cultural pattern (Duelli & Obrist, 2003). This increase coincided with a rise in daily maximum temperatures, which consistently exceeded 20°C. Higher temperature is positively correlated with cereal aphid populations, because of elevated immigration, reproduction, survival, and development rates (Kieckhefer & Elliott, 1989; Thies et al., 2005; Jan et al., 2017). It is important to note that after Z6 sampling, a 30 mm rainfall occurred. According to Beirne (1970), heavy precipitation can cause sudden, marked, and often catastrophic decreases in small insects, such as aphids. They may be drowned on the plants or dislodged by the impact of raindrops, potentially drowning in surface water or in water collected in leaf axils or at least becoming unable to return to the plants. Additionally, the maximum abundance of its predators, the coccinellids, was recorded at Z7 which contributes to reducing aphid density at the time of their maximun population (Honek & Martinkova, 2004). Also, at these stages, the senescense crop starts and spreading of entomopathogenic fungi could happen (Ahmad et al., 2016) and emigration of alatae aphids because of host suitability (Honek & Martinkova, 2004). Other factors contributing to aphid population reduction should also be considered, including parasitism and other predators (unpublished data), that were recorded and may have acted synergistically to enhance aphid suppression. These factors could explain the reduction in aphid abundance in Z7 and Z8. During this period, as aphid abundance decreased, their distribution pattern changed, exhibiting an Ubiquist pattern (Duelli & Obrist, 2003).

This study demonstrated variability in aphid distribution patterns among the AFD and wheat, influenced by the wheat cycle. The hypothesis that there is an increase in aphid population in the wheat crop at greater distances from the AFD is only accepted when significant increases in aphid populations are observed. When these densities were low during colonization and at the end of the crop cycle, distribution patterns exhibited Dispersal and Ubiquist characteristics, respectively. While our review has not revealed any study indicating temporal changes in aphid distribution patterns relative to the distance from the AFD, evidence exists demonstrating that this pattern can be variable. Bowie et al. (1999) found that *Rhopalosiphum padi* were less numerous at the margins than at distances of 64 meters or more into a wheat crop. In contrast, Hausammann (1996), in two years of studying wheat, did not find an increase in aphid abundance at greater distances from weed strips. In lucerne, Villegas et al. (2013) determined that there were no significant differences in the mean abundance of aphids at varying distances from a field edge.

Coccinellids in wheat and AFD

Harmonia axyridis was the first species to arrive and showed higher abundance in AFD, whereas *E. connexa* arrived later and was more abundant in the wheat crop. *C. ancoralis* was the last species to arrive in the crop and showed no preference between the AFD and the crop.

Similar results were reported by Tulli (2010) in Balcarce, Argentina, where *E. connexa* predominated while *H. axyridis* maintained lower population levels in wheat. Habitat selection in coccinellids may be influenced by various factors, including trophic specificity, competition for prey, the costs associated with habitat and prey shifts, predator-prey size relationships, and the nutritional quality of available food, among others (Hodek, 2012). The environments studied were different, with AFD areas exhibiting greater aphid and invertebrate diversity than wheat fields (unpublished data). Larger coccinellid species, such as *H. axyridis*, exhibit a broader trophic niche, preying not only on aphids but also on other invertebrates, including lepidopteran larvae (Hodek, 2012). This broader diet, combined with its larger body size, may explain its earlier colonization and establishment compared to other coccinellid species. According to Hesler & Beckendorf (2021), *H. axyridis* prefers soybean crops and, to a lesser extent, early-season habitats such as wheat, suggesting that it may also utilize alternative early-season habitats, potentially in arboreal environments. In contrast, *E. connexa* exhibited lower abundance in AFD. The establishment of *H. axyridis*, a species known for its high competitiveness and predation on other native coccinellids (Koch, 2003; Koch et al., 2006), could partially explain the lower abundance of *E. connexa* in these areas. Additionally, *E. connexa* may be more specialized in exploiting aphid populations within the crop, which could further contribute to its preference for wheat fields. Finally, the low density of *C. ancoralis* in both the AFD and the crop may be explained by its later arrival compared to the other species. What is more, both *H. axyridis* and *E. connexa* are larger in size than *C. ancoralis* and this could be the cause of its competitive displacement.

Coccinellid spatial distribution in relation to wheat cycle

The arrival and increase of coccinellids in the crop were related to the aphid fluctuation. No coccinellids were recorded in the AFD when aphid colonization of wheat began. These areas were colonized later, when significant increases in aphid abundance were observed in both habitats. This suggests that vegetation from the AFD may not have provided sufficient or suitable shelter to support coccinellids overwintering. During unfavorable conditions such as cold weather and food scarcity (winter), coccinellids enter a dormancy period, selecting appropriate habitats for overwintering. There is a considerable variation in coccinellids dormancy behavior; some species overwinter on their preferred host plants, while others migrate long distances from feeding and breeding sites to dormancy sites (Majerus et al., 2016). Coccinellids overwinter in diverse locations, including rock crevices, heaps of stones, leaf litter, tree bases, cones, grass tussocks, standing dry herbs, as well as buildings and other artificial structures (Honek et al., 2007; Holecová et al., 2018). Certain species may use various overwintering sites but often show a preference for specific types (Holecová et al., 2018). The subsequent presence of coccinellids in the AFD and wheat later in the season may be a consequence of adult migration from other areas. This movement typically occurs soon after the emergence of the first adult generation, during the initial warm days after winter (Iperti, 1999). Elliott et al., (2000) observed that short flights in different coccinellids increases rapidly when temperatures exceed 16 °C. In this study, mean temperatures remained below 16 °C on most dates between Z2 and Z3, which may have limited coccinellid flight activity. As aphid abundance in the crop increased from Z39 onwards, coupled with rising temperatures, the density and diversity of coccinellids also increased. In fact, they reached their peak abundance at Z7, approximately one month after the aphid population began to rise.

The dispersal pattern of coccinellids has been described by Hodek (2012) as a step-wise process. They initially fly from their dormancy sites to adjacent fields and, if aphids are present, only gradually disperse further. This was the case for *E. connexa* and *H. axyridis*, whose abundances during colonization were higher in the AFD. In contrast, *C. ancoralis* primarily colonized the wheat crop, as the AFD showed a lower abundance than 60 meters inside the crop. After colonization, the abundance of *E. connexa* and *H. axyridis* increased, and dispersed throughout the crop, but their distribution varied with increasing distance. *H. axyridis* exhibited an Ecotone pattern (Duelli & Obrist, 2003), as it showed a preference for the edge areas and was never recorded at distances greater than 40 meters. In contrast, between Z7 and Z8, *E. connexa* displayed a Cultural pattern (Duelli & Obrist, 2003); as it was found exclusively within the crop, in all distances evaluated. Contrary to this assay, Olson & Wäckers (2007) found *H. axyridis* in field margins before cotton planting and its density increased with distance from this, as far as 75 meters. The margins of these fields likely contain plant species and hosts that support overwintering and reproduction for this coccinellid, which may partially explain the difference in distribution patterns. According to Olson & Wäckers (2007), individual responses may be understood in terms of arthropod-specific resource requirements.

This research demonstrated variability in habitat preference, coccinellid arrival to the crop, and species-specific distribution patterns. Therefore, the hypothesis that coccinellid populations in wheat decrease at greater distances from the AFD was accepted only for *H. axyridis*. The native coccinellids *E. connexa* and *C. ancoralis* were recorded at most of the evaluated distances, with no evidence of a decline in abundance throughout these.

Final considerations. The success of biological control is more likely when prey and predators overlap in space and time; therefore, pest and natural enemy distributions need to be considered in biological control strategies (Park & Obrycki, 2004). To enhance biological control of arthropod pests in crops, Wiedenmann & Smith (1997) emphasize the importance of the natural enemy's dispersal capacity, both within crops and between the crop and the AFD. For effective arthropod pest suppression, natural enemies must either have a uniform distribution from the AFD to the crop (Ubiquist pattern) or show a preference for the crop (Cultural pattern) (Duelli & Obrist, 2003; Oberg & Ekbom, 2006). Given that aphids in wheat exhibited a Cultural pattern, the native coccinellids *E. connexa* and *C. ancoralis* appear to be promising candidates. These species could help regulate changes in aphid abundance across space and time.

Movement is fundamental to most organisms, beingnecessary for their survival. For entomophagous arthropods living in dynamic agricultural landscapes, movement is critical for locating mates and food, finding reproduction sites, and avoiding mortality from agricultural practices (Schellhorn et al., 2014). In this study, it was found that coccinellids colonized wheat crops from other overwintering sites in the surrounding agricultural landscape, and the crop acted as a temporary feeding site, increasing their abundance. At the end of the wheat cycle, the density of aphids decreased, leading to a corresponding decline in coccinellid abundance. It is likely that coccinellids migrate to other areas or nearby crops in search of food resources, such as pollen and prey. In the southeast of Buenos Aires province, the authors have observed that coccinellids migrate to other nearby crops, such as potato and sunflower, after the wheat harvest. Later, during unfavorable weather and food scarcity in winter, coccinellids move to suitable overwintering habitats. Areas of AFD that are not plowed or otherwise disturbed during autumn or winter can serve as refuges and hibernation sites for coccinellids and many other arthropods. Consequently, to promote the presence of coccinellids in AFD during winter, it is essential to understand the overwintering ecology of *E. connexa* and *C. ancoralis*. This understanding will allow for the management of AFD areas and the selection of native botanical species to maximize overwinter survival. Ultimately, this will enhance their early colonization of wheat and other winter crops during the initial development of aphid populations. Finally, the documented increase in aphid density toward the center of the crop during the critical period of yield determination emphasizes the need to monitor aphid populations, including areas near the crop center. This approach will allow for a better understanding of their abundance distribution across the field and help avoid the potential error of underestimating their actual density.

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