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Abstract. Winter canola (*Brassica napus* L.) is planted in late September through October in central Oklahoma and harvested in June. Three aphid species typically infest canola fields in central Oklahoma: cabbage aphid, *Brevicoryne brassicae* L.; green peach aphid, *Myzus persicae* (Sulzer); and turnip aphid, *Lipaphis pseudobrassicae* (Davis). Predatory insects and spiders and hymenopteran parasitoids that prey on aphids are present in canola fields in central Oklahoma. We used a D-vac suction device to sample aphids and natural enemies in a total of 23 canola fields in central Oklahoma in early November and mid-March of three growing seasons. During the three growing seasons, 2.4 to 50.9 aphids were collected per 120 placements of the D-vac sampler per canola field. *Diaeretiella rapae* (McIntosh) was the most abundant parasitoid, with 0.04 to 5.1 individuals per 120 placements, while Araneae (spiders) were the most abundant predators ranging from 0.35 to 4.9 per 120 placements. Other predators were Chrysopidae, Hemerobiidae, Nabidae, and Syrphidae, with relative density of most taxa increasing from November to March. Correlations of relative density of *D. rapae* and larval Coccinellidae to aphid relative density were positive and significant suggesting the taxa had a reproductive and/or aggregative numerical response to aphids in canola. *D. rapae*, Coccinellidae, and perhaps spiders killed the most aphids in central Oklahoma canola fields.

Introduction

Winter canola (*Brassica napus* L.) production in Oklahoma increased from 0 to approximately 80,000 ha from the early 2000s to 2015, but decreased in recent years with only 4,860 ha grown in 2020 (USDA NASS 2020). Annual outbreaks of aphids in canola are common and three aphid species typically infest canola fields in central Oklahoma and elsewhere in the south-central US: cabbage aphid, *Brevicoryne brassicae* L.; green peach aphid, *Myzus persicae* (Sulzer); and turnip aphid, *Lipaphis pseudobrassicae* (Davis) (Boyd and Lentz 1994, Royer and Giles 2017a). Aphids in canola are important pests that severely reduce grain yield potential of canola in Oklahoma (Royer and Giles 2017a,b). Jessie (2017) used sticky

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traps in canola fields and documented aphid natural enemies moving within the boundary layer above canola in central Oklahoma. Predatory insects from seven families and Araneae known to prey on aphids were captured on the sticky traps. Parasitoid species *Diaeretiella rapae* (McIntosh) and *Lysiphlebus testaceipes* (Cresson) were encountered on traps. *Diaeretiella rapae* is the most common parasitoid of the three aphid species in canola in central Oklahoma (French et al. 2001, Elliott et al. 2014a,b).

The D-vac® suction sampler (Dietrick 1961) has been used to sample insects in a variety of habitats including *B. napus* (Slosser et al. 2000, Williams et al. 2003) and is useful for obtaining estimates of relative density of many insect species in a variety of habitats (Southwood and Henderson 2000). The D-vac is useful and efficient for sampling pest insects and parasitoids in canola (Williams et al. 2003). The D-vac is efficient for aphids, aphid parasitoids, and small predators or predators with large surface areas relative to their weight, but probably not efficient at sampling relatively heavy, compact insects such as adults of most coccinellids and carabids (Southwood and Henderson 2000, Elliott et al. 2006). Other aphidophagous arthropods in canola are relatively small (e.g., Anthocoridae) or light-weight (e.g., Chrysopidae) and are probably efficiently captured by a D-vac.

Our objective was to quantify aphid and natural enemy relative density and variation of relative density in central Oklahoma canola fields among growing seasons and in autumn versus spring. A D-vac suction sampler was used to obtain samples of a broad range of insects and other arthropods from commercial canola fields in November and March of each of three growing seasons.

Materials and Methods

Seven commercial canola fields in central Oklahoma were sampled in November and again the following March during the 2016-2017 growing season and eight fields in the 2017-2018 and 2018-2019 growing seasons. A backpack 24 D-Vac® (Rincon-Vitova Insectaries, Ventura, CA) suction sampler fitted with a standard 33-cm-diameter collecting unit, fine mesh organdy collecting bag, and fiberglass collar was used to sample aphids and natural enemies in canola fields.

A subsample of 20 placements of the D-Vac unit was collected along each of three parallel transects approximately 100 m long for a total of 60 placements per field and total area sampled of 51,292 cm^2. Transects were approximately 25 m apart, perpendicular to the nearest field edge, and started 10 m from the edge of the field. Approximately every 5 m along each transect, the D-vac collecting head was placed straight down over each of 20 growing canola plants to just above the surface of the soil. The collecting unit was placed down and held in position slightly above the soil surface for 5 seconds each time. The sampling bag was removed from the D-vac after 20 placements and all arthropods collected were put into a labeled plastic bag. Bags were brought to the laboratory and frozen until processed. The numbers of aphids and natural enemies in each of several categories were counted for the three subsamples, and the counts for the three sub-samples were summed. All aphids were counted but not identified to species because of difficultly in rapid identification of frozen aphids. Some natural enemies were identified to species but for others the number of individuals in broader taxonomic groups were recorded. Thus, there was a single number for aphids and for each natural enemy species or category for each field on a particular sampling date. Mean counts were based on the 60-placement sample for each field in November or March. When comparing the three growing seasons, counts from November and March were pooled (total of 120 placements per field). PROC MEANS (SAS Institute 2004) was used to calculate descriptive statistics. PROC CORR at α = 0.05 significance (SAS Institute 2004) was used to calculate Pearson correlation coefficients for aphid relative density to natural enemy relative density for autumn and spring.

Results and Discussion

During the three growing seasons, aphid relative density in canola ranged from 2.4 (2018-2019) to 50.9 (2017-2018) per 120 placements of the D-vac sampler (Table 1). Adults of three species of parasitoid, *D. rapae*, *L. testaceipes*, and *Aphelinus nigritus* Howard, were captured by D-vac. The parasitoid species are similar in size, weight, and morphology and probably captured with similar efficiency by D-vac. Adult parasitoids were not captured in canola in autumn but were captured in spring (Table 2). *Diaeretiella rapae* was the most abundant species, ranging from 0.04 individuals per 120 D-vac placements in 2018-2019 to 5.1 individuals in 2016-2017 (Table 1). *Lysiphlebus testaceipes* was the second most abundant parasitoid in 2016-2017 and 2017-2018, while *A. nigritus* was captured only during the 2017-2018 growing season and in very low numbers (mean of 0.04 individual per 120 placements). *Lysiphlebus testaceipes* accounted for less than 2% of all aphid parasitoids captured in canola, while *D. rapae* accounted for more than 98%. This contrasts with numbers of each parasitoid species captured on sticky traps above the canopy in canola fields in

Table 1. Average Number (± SE) of Aphids and Natural Enemies per Field with Transects Sampled by D-vac in Canola in Central Oklahoma

	2016-2017	2017-2018	2018-2019
Number of fields (n)	7	8	8
Adult predators			
H. convergens	0.06 ± 0.06	0.00	0.00
C. septempunctata	0.06 ± 0.06	0.00	0.04 ± 0.04
C. maculata	0.00	0.00	0.00
Chrysopidae	1.69 ± 0.35	0.12 ± 0.08	0.23 ± 0.10
Hemerobiidae	0.13 ± 0.08	0.00	0.00
Adult parasitoids			
L. testaceipes	0.06 ± 0.06	0.08 ± 0.08	0.00
D. rapae	5.13 ± 2.58	3.59 ± 1.58	0.04 ± 0.04
A. nigritus	0.00	0.04 ± 0.04	0.00
Larvae			
Coccinellidae	0.19 ± 0.13	0.08 ± 0.08	0.00
Chrysopidae	0.00	0.04 ± 0.04	0.00
Hemerobiidae	0.00	0.00	0.00
Syrphidae	0.00	0.00	0.08 ± 0.05
Adult + larva			
Aphids	46.00 ± 19.2	50.86 ± 31.36	2.38 ± 0.39
Araneae	4.88 ± 1.22	0.35 ± 0.19	1.76 ± 0.29
Nabidae	0.13 ± 0.13	0.00	0.00
Orius sp.	1.06 ± 0.38	0.08 ± 0.08	0.00

central Oklahoma where *L. testaceipes* accounted for more than 99% of aphid parasitoids captured with *D. rapae* less than 1% (Jessie 2017). Although *L. testaceipes* is abundant in aerial samples from the boundary layer directly above canola plants it is an infrequent inhabitant of canola. Thus, it is unlikely that *L. testaceipes* preys on aphids in canola or does so infrequently. Our observation is consistent with previous studies in which *D. rapae* was the only parasitoid reared from aphids infesting canola fields in central Oklahoma (Elliott et al. 2014a,b). *Aphelinus nigritus* was captured only during spring of the 2017-2018 growing season. While *A. nigritus* is a frequent inhabitant in wheat (*Triticum aestivum* L.) fields in central Oklahoma (Giles et al. 2021), it is not consistently abundant in canola.

Table 2. Average Number (± SE) of Aphids and Natural Enemies from D-vac Suction Samples of 60 Placements of the D-vac Head in Transects in a Canola Field in Central Oklahoma

Number of fields (n)	23	23
Enemy / life stage	**November**	**March**
Adult predators		
H. convergens	0.00	0.05 ± 0.05
C. septempunctata	0.00	0.10 ± 0.07
C. maculate	0.00	0.00
Chrysopidae	0.67 ± 0.52	1.19 ± 0.42
Hemerobiidae	0.10 ± 0.07	0.00
Adult parasitoids		
L. testaceipes	0.00	0.19 ± 0.11
D. rapae	0.00	9.90 ± 3.58
A. nigritus	0.00	0.05 ± 0.05
Larva		
Coccinellidae	0.010 ± 0.10	0.14 ± 0.08
Chrysopidae	0.05 ± 0.05	0.00
Hemerobiidae	0.00	0.00
Syrphidae	0.00	0.14 ± 0.07
Adult + larva		
Aphids	15.67 ± 3.92	105.1 ± 50.52
Araneae	3.62 ± 1.66	3.81 ± 0.85
Nabidae	0.10 ± 0.10	0.00
Orius sp.	0.14 ± 0.10	0.86 ± 0.47

Averages were calculated from numbers of individuals per 60-placement D-Vac sample for each of 23 fields sampled during November and March.

Few adult Coccinellidae (*Hippodamia convergens* Guerin-Meneville and *Coccinella septempunctata* L.) were captured during the study, probably because of low capture efficiency of the D-vac (Elliott et al. 2006). Coccinellid larvae were captured in autumn and spring during two of three growing seasons (Table 2). Thus, coccinellids reproduced in canola fields during both seasons. Among other aphid predators, adult Chrysopidae (primarily *Chrysoperla carnea* (Stephens)), Hemerobiidae, Araneae (spiders), *Orius* sp. (probably *Orius insidiosus* (Say)), and Nabidae were in samples from canola fields (Table 1). With the exception of adult Chrysopidae and spiders, no additional predator was abundant in samples. The relatively high numbers of adult Chrysopidae captured compared to other natural enemies was partly the result of very high sampling efficiency of D-vac suction sampling for adult Chrysopidae (Elliott et al. 2006). However, the consistency with which adult Chrysopidae were captured indicated they frequently inhabit canola fields during the growing season. Relative density of larval Chrysopidae was very low with immatures captured only during the 2017-2018 growing season (Table 1) and only during autumn (Table 2). This contrasts with a contemporaneous study in winter wheat in central Oklahoma using similar sampling methods where immature chrysopids were relatively abundant in both autumn and spring (Elliott et al. 2021). Our results suggest that Chrysopidae are not usually important predators of aphids in canola in central Oklahoma.

Spiders were relatively abundant during each of the three growing seasons (Table 1) and similarly abundant in both autumn and spring (Table 2). Although spiders are generalist predators that feed on a broad range of arthropod prey (Greenstone 2001, Nyffeler and Sunderland 2003), their relative abundance in canola fields in central Oklahoma suggests they might be among the more important natural enemies of aphids in the crop. Abundance of coccinellid larvae was positively correlated with aphid abundance in spring ($r = 0.78$) but not in autumn (Table 3). An aggregative and reproductive numerical response by adult Coccinellidae to aphid density is well documented in the literature (Obrycki and Kring 1998 and references therein). The relatively consistent occurrence of coccinellid larvae in canola and reproductive numerical response to aphid abundance combined with well-documented high voracity on aphids indicated that Coccinellidae contribute to biological control of aphids in canola in central Oklahoma.

Table 3. Correlation of Number of Aphids to Number of Natural Enemies per 60-Placement D-vac Sample in November and March of Three Growing Seasons in Canola Fields in Central Oklahoma

Number of fields sampled	23	23
Aphid enemy	**November**	**March**
Adult *H. convergens*	-	0.03
Adult *C. septempunctata*	-	-0.05
Adult *C. maculate*	-	-
Adult Chrysopidae	0.57*	0.09
Adult Hemerobiidae	0.24	-
Adult *L. testaceipes*	-	-0.13
Adult *D. rapae*	-	0.66*
Adult *A. nigritus*	-	-0.09
Larval Coccinellidae	0.14	0.78*
Larval Chrysopidae	0.05	-
Larval Hemerobiidae	-	-
Larval Syrphidae	-	-0.11
Araneae	0.36	-0.18
Nabis	-0.02	-
Orius	0.28	0.28

*significant correlation

Diaeretiella rapae relative density was significantly correlated (*r* = 0.66) to aphid relative density in spring (Table 3), suggesting that *D. rapae* had a numerical response to aphid density in canola fields. Previous research documented both functional and numerical responses by *D. rapae* to aphids in canola (Nematollahi et al. 2014, Karami et al. 2018). *Diaeretiella rapae* parasitizes aphids in a broad range of habitats including wheat and non-cultivated grasses on the U.S. Great Plains (Vaughn et al. 1996, Elliott et al. 2019). However, it is primarily a parasitoid of aphids on cruciferous plants, the volatiles of which are attractive to foraging females (Read et al. 1970, Reed et al. 1995, Vaughn et al. 1996). Parasitism of aphids by *D. rapae* in wheat in Oklahoma is always low typically accounting for less than 1% of total parasitoids emerging from hosts in wheat (Giles et al. 2021). Parasitism levels by *D. rapae* on aphids in non-cultivated grasses also seem low (Elliott et al. 2019), although the relationship is not well studied. *Diaeretiella rapae* colonizes canola in central Oklahoma but colonization occurs slowly compared to the occurrence of aphids in the crop. Slow colonization could be the result of a limited source of aphid hosts for *D. rapae* in the landscape because no other cruciferous crops commonly are grown in central Oklahoma. There are over 60 species of wild crucifers in Oklahoma (Folley 2011), some of which are common (e.g., wild mustard, *Brassica haber* (DC.)). What role they play in hosting aphids and *D. rapae* is unknown.

Correlation of adult Chrysopidae to aphid relative density was positive and significant in autumn but not in spring (Table 3). Adult *C. carnea*, the dominant chrysopid in Oklahoma agroecosystems, make multiple appetitive flights until they encounter a scent plume with kairomones signaling honeydew from aphid prey. They settle in such habitats which leads to aggregation in habitats with aphids (Duelli 1984). This could explain the positive correlation of chrysopid to aphid relative density in canola in autumn. Lack of correlation in spring is difficult to explain but could relate to variation in relative quality of resources in other habitats. For example, wheat is the dominant winter crop in central Oklahoma and exceeds canola in total hectarage by about 10 times (USDA, NASS 2020). Wheat fields in central Oklahoma are typically infested with cereal aphids that increase in relative density from autumn to spring (Elliott et al. 2018) and might be a more attractive habitat than canola for chrysopids in spring. Frequent use of insecticides in canola primarily to control aphids and diamondback moth, *Plutella xylostella* (L.) (Royer and Giles 2017a,b) might obscure predator-prey interactions in canola fields and at least partially account for lack of correlation between natural enemy and aphid relative abundance in canola.

Results suggested that *D. rapae* might be the most consistent and important natural enemy of aphids in canola, with coccinellids and spiders also important. Although spiders are generalist predators their consistent abundance in canola fields suggests they might be important, especially during colonization by aphids in canola fields because they are present and abundant when aphids initially colonize the crop (Nyffeler and Sunderland 2003). Biological control of aphids in canola fields in central Oklahoma might be the combined result of mortality exerted by a complex of natural enemies as was observed in other agroecosystems (Frazer et al. 1981, Snyder and Ives 2003); however, additional study is required to elucidate relationships.

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