Diversity of Aphidophagous Natural Enemy Guild in Maize

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ANIL MEENA

Thesis

Master of Science in Agriculture
(Entomology)

2014

DEPARTMENT OF ENTOMOLOGY
RAJASTHAN COLLEGE OF AGRICULTURE
MAHARANA PRATAP UNIVERSITY OF AGRICULTURE AND TECHNOLOGY
UDAIPUR – 313001 (RAJ.)

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Thesis
Submitted to the

Maharana Pratap University of Agriculture & Technology, Udaipur
in partial fulfillment of the requirements for the degree of

Master of Science in Agriculture
(Entomology)

By

ANIL MEENA

2014

MAHARANA PRATAP UNIVERSITY OF AGRICULTURE AND TECHNOLOGY, UDAIPUR

RAJASTHAN COLLEGE OF AGRICULTURE, UDAIPUR

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Dated: /   /2014

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This is to certify that the thesis entitled **"Diversity of Aphidophagous Natural Enemy Guild in Maize"** submitted for the degree of **Master of Science in Agriculture** in the subject of **Entomology,** embodies bonafide research work carried out by **Mr. ANIL MEENA** under my guidance and supervision and that no part of this thesis has been submitted for any other degree. The assistance and help received during the course of investigation have been fully acknowledged. The advisory committee also approved the draft of this thesis on _____________.

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This is to certify that **Mr. ANIL MEENA** student of the **Department of Entomology**, Rajasthan College of Agriculture, Udaipur has made all corrections /modifications in the thesis entitled **"Diversity of Aphidophagous Natural Enemy Guild in Maize"** which were suggested by the external examiner and the advisory committee in the oral examination held on___________ The final copies of the thesis duly bound and corrected were submitted on_________ are enclosed herewith for approval.

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CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF PLATES

LIST OF APPENDICES

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Diversity of Aphidophagous Natural Enemy Guild in Maize

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ABSTRACT

The present investigation on, "*Diversity of aphidophagous natural enemy guild in maize*" was carried out at the Instructional Farm, Rajasthan College of Agriculture, Udaipur during summer (*zaid*) (April to July, 2013) and *kharif* (July to October, 2013) seasons with the objectives to study the diversity of aphids of maize and their natural enemies and evaluate the predation potential of major insect groups of the aphidophagous guild in the field and laboratory. The major aphid recorded on maize was *Rhopalosiphum maidis* (Fitch) and on cowpea (as an intercrop) was *Aphis craccivora* (Koch). Among the aphidophagous natural enemy guild, the major insect groups included coccinellids (*C. septempunctata*, *Cheilomenes sexmaculatus*, *B. suturalis* and *I. cincta*: Coccinellidae, Coleoptera); lygaeid bug (*Geocoris* sp.: Lygaeidae, Hemiptera,); rove beetle [*Paederus fuscipes* Curtis: Staphylindae, Coleoptera] and syrphid flies (*Ischiodon* sp.: Syrphidae, Diptera; being dominant). The seasonal mean population of aphids was higher during *kharif* season crop (369.09/plant) than during the summer season (291.26/plant). Likewise, the seasonal mean population of the natural enemy guild per plant was relatively more during *kharif* season being 8.56 (coccinellids), 3.76 (*Geocoris* sp.), 3.14 (*P. fuscipes*) and 2.41 (syrphid flies); whereas, in summer (*jhaid*) season the corresponding values were 7.78 (coccinellids), 3.60 (*Geocoris* sp.), 2.87 (*P. fuscipes*) and 1.89 (syrphid flies). Exclusion of the ground dwelling aphidophagous predators resulted into significantly more aphid predation (99.75%) than when aerial aphidophagous predators were excluded from access to aphid prey (89.38%). In the no exclusion treatment, where both types of predators (aerial and ground dwelling) had equal access to aphid prey, the decrease in aphid numbers was the maximum (100%). All the three coccinellid grubs and adult beetles consumed relatively more aphids at lower aphid densities (25, 50 and 75), significantly being the maximum at a prey density of 75. At higher aphid densities (100, 125 and 150) the consumption rates declined. The feeding behavior of coccinellids showed a sharp decline in percentage feeding with an increase in prey density for both adults and grubs.

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1. INTRODUCTION

The large-scale biodiversity losses in agricultural landscapes may negatively affect the flow of ecosystem services such as biological control, which is exerted by a wide range of natural enemies, particularly arthropods (Caballero-Lopez *et al*., 2012). Agro-ecosystems under intensive agriculture often present unfavourable environments for natural enemies due to high levels of anthropological disturbance, particularly through intensive agriculture. Habitat management that aims at utilizing practices to favour natural enemies, especially, predators and parasitoids towards achieving conservation biological control has been often advocated. Evidence from previous studies suggests that non-cropped habitats close to crop fields play a crucial role in maintaining natural enemy diversity in agro-ecosystems (Gurr *et al*., 2003; Bianchi *et al*., 2006; Tscharantke *et al*., 2007; Griffiths *et al*., 2008; Gardiner *et al*., 2009; Werling and Gratton, 2010). A higher natural enemy abundance (Ostman *et al*., 2001) or diversity (Snyder *et al*., 2006) may not automatically lead to improved biological control, because prey other than the pest species may be preferred.

The corn leaf aphid, *Rhopalosiphum maidis* (Fitch) is one of the important pests of maize with worldwide distribution (Carena and Glogoza, 2004; Razmjou and Golizadeh, 2010). Al-Eryan and El-Tabbakh (2004) estimated the losses caused by maize aphids and observed that infestation from 10-leaf stage to tasseling caused 28.14 per cent yield losses (average aphid density 818 aphids/plant); while, infestation through ripening stages caused 16.28 per cent yield losses (average aphid density 1038 aphids per plant). Yield losses of corn due to aphid infestation from 10-leaf stage to ripening stage were 14.66, 22.9, 35.28 and 36.03 per cent at average aphid densities of 100, 1000, 2000 and 3000 aphids per plant. This clearly indicates that plant lice, *i.e.*, aphids can cause considerable losses to the crop and thus must be managed through eco-safe methods. The management of sap sucking insect pests through bio-intensive methods renders it important to record the diversity of natural enemies of aphids, both generalist and specific, commonly occurring in any crop ecosystem to exploit them in favour.

The aphidophagous arthropod guild can be divided broadly into specialists that include Braconidae and Aphidiinae parasitoids; predatory coccinellids, lacewings and hoverflies (Muller and Godfray, 1999) or generalists that include euryphagous predators like ground beetles and spiders (Lang, 2003). Intra-guild competition is often reported among aphidophagous natural enemies due to their foraging activity when they frequently encounter hetero-specific aphid predators, which may disrupt biological control efforts against aphids where more than one predator species is present; hence, this necessitates carefully choosing a combination of predators for success in biological control of aphids (Hindayana *et al*., 2001). The present investigation thus envisages working out the diversity of aphidophagous arthropod natural enemies in maize cultivated during summer and in the *kharif* season. Keeping these points in view, the present investigation entitled, "*Diversity of aphidophagous natural enemy guild in maize*" was under taken with the following objectives:

i. To study the diversity of aphid pests of maize and their natural enemies.

ii. To evaluate the predation potential of major insect groups of the aphidophagous guild.

iii. To compare the efficacy of the aphidophagous guild in summer and *kharif* maize.

2. REVIEW OF LITERATURE

The available literature on different objectives of the research work has been compiled and presented in this chapter. Knowledge of insect biodiversity and patterns of distribution becomes necessary for a better understanding of insect ecology and behavior, as well as to design sampling programs for rapidly assessing pest density and phenological forecasting. The management of sap sucking insect pests through bio-intensive methods renders it important to record the diversity of natural enemies, both generalist and specific, commonly occurring in any crop ecosystem to exploit them in favour. Estimating the losses due to aphid infestation in maize, Al-Eryan and El-Tabbakh (2004) reported that infestation with aphids from 10-leaf stage to tasseling caused 28.14 per cent yield losses when the average aphid density was 818 aphids per plant. Infestation through ripening stages caused 16.28 per cent yield losses when the average aphid density was 1038 aphids per plant. Yield losses of corn due to aphid infestation from 10-leaf stage to ripening stage were 14.66, 22.9, 35.28 and 36.03 per cent at average aphid densities of 100, 1000, 2000 and 3000 aphids per plant.

2.1 Diversity of aphids and their natural enemies:

Coderre and Tourneur (1988) recorded the abundance of the aphids *Rhopalosiphum maidis*, *R. padi*, *Sitobion avenae* and *Metopolophium dirhodum* and aphid predators, especially *Coccinella septempunctata*, *Coleomegilla maculata*, *Hippodamia tredecimpunctata*, *Hemerobius humulinus* and *Sphaerophoria philanthus*, in 2 maize monocultures in southern Quebec was investigated in 1978-82. The 2 species of *Rhopalosiphum* were the dominant aphids, and showed a bimodal seasonal distribution, with a decrease in abundance at the end of July. Climatic factors and emigration could not explain this decrease, but was probably related to diminished plant nutritional quality and an increase in predation. Studying the influence of intercropping in maize, Coderre *et al.* (1989) observed that the abundance of *Metopolophium dirhodum* on maize plants in a maize monoculture in Quebec was higher than on maize intercropped with beans, but the abundance of *Rhopalosiphum maidis* and *R. padi* did not differ significantly between the

2 treatments. Among predators, the coccinellids, *Coleomegilla maculata lengi* and *Hippodamia tredecimpunctata* were significantly more abundant in the monoculture than in the maize intercropped with beans, but *Coccinella septempunctata* and spiders were not. The presence of bean plants in the diculture influenced primarily those aphids which exploit the lowest stratum of the maize plant. The results for predators contradict prevailing ecological theory, which predicts higher densities of predators in polycultures than in monocultures. Differences in coccinellid population densities were caused by different aphid abundances in monoculture.

Voicu (1989) observed *Rhopalosiphum maidis* on maize from 3 regions of Romania to be controlled by 23 species of predatory insects, including 2 anthocorids, 3 nabids, 2 chrysopids, a cantharid, 2 malachiids, 10 coccinellids and 3 syrphids. In a study on the aphids and aphidophages in Poland, Plewa and Pankanin-Franczyk (1989) recorded *Metopolophium dirhodum*, *Sitobion avenae* and *Rhopalosiphum padi* with 2 peaks in aphid numbers. Coccinellids (4 species) and chrysopids (3 species) as the most abundant predators, followed by syrphids and nabids, and 6 species of aphidiid [Braconidae] parasitoids. Asin and Pons (1998) monitored the potential aphid-predatory fauna weekly in commercial fields of maize, using visual counts and pitfall traps. They observed that though coccinellids (*Coccinella septempunctata*, *Adonia variegata*, *Propylaea quatuordecimpunctata*) were the most common aphid-specific predators, polyphagous predators were more abundant, mainly anthocorids (*Orius* spp.), carabids (*Demetrias atricapillus*, *Harpalus rufipes*, *Bembidion* spp., *Poecillus cupreus*, *Agonum dorsale*), dermapterans (*Labidura riparia*, *Forficula auricularia*), nabids (*Nabis provencalis*) and spiders. The aphidophagy test for the potential polyphagous predators indicated that nearly all species tested were able to consume aphids, especially *N. provencalis*, *Orius* spp., *F. auricularia*, *L. riparia* and *D. atricapillus*. According to Paulian (1999) the relatively more common aphidophagous predators on maize belonged to the insect families Chrysopidae, Coccinellidae, Nabidae and Syrphidae. Type of soil, forerunner crops and fertilizers affected the dynamics of the aphid-predator system in Romania. The chrysopids constituted 48 per cent of the predator guild and comprised *Chrysoperla kolthoffi* and *C. lucasina*. The coccinellids constituted 36 per cent of the predator guild and the dominant species was *Coccinella septempunctata*.

Chrysopids established earlier while the ladybirds later, only if plants were strongly colonized by aphids.

The dynamics of natural populations of *Rhopalosiphum padi* (Linnaeus) were investigated by Li SuJian *et al.* (2000) for 6 generations in 2 years, and a life table was established for each generation. Analysis on the influencing factors showed that weather and natural enemies were two major factors responsible for population changes. The aphid showed a 22.46 – 50.00 per cent decrease of 1-2 instar nymphs caused by winds and rains. The predators, *Coccinella septempunctata* and hover flies [Syrphidae] had a significant effect on its population dynamics. *C. septempunctata* occurred in the same season as the aphid infestation and showed a predation rate of 265 heads per day. Infestation of maize in Upper Egypt with *Schizaphis graminum* and *Rhopalosiphum maidis* in 1988 and 1989 occurred at the beginning of August, and the aphids reached their maximum abundance (406 and 518 per plant) in the 4^{th} week of August, when the plants were in their reproductive stage. Aphid populations began to decrease from the 3^{rd} week of September, to reach their lowest levels in mid-October, when the plants were mature. The commonest predators associated with aphids were *Orius* spp., *Coccinella undecimpunctata*, *Scymnus* spp., *Chrysoperla carnea* and spiders. These predators comprised about 88 per cent of the total natural enemies in both seasons (Darwish and Ali, 2001).

Coccinellids, one of the more important predators of sucking pests like aphids, jassids [Cicadellidae], thrips, scales [Coccoidea], mealy bugs [Pseudococcidae], pyrilla, plant hoppers, white flies [Aleyrodidae] and lepidopteran eggs and neonate larvae are widely distributed in India with 77 species reported from different parts of the country. Of these, *Coccinella septempunctata*, *Coccinella transversalis*, *Brumoides suturalis* and *Menochilus sexmaculatus* [*Cheilomenes sexmaculata*] are reportedly the most widespread (Jagmohan Singh and Brar, 2004). Three widely used biodiversity indices (Shannon-Wiener, Simpson-Yule and Berger-Parker) were used to measure the diversity of a community with 3 abundant coleopteran insects in rice (*Paederus fuscipes*, *Altica cyanea* and *Coccinella septempunctata*) and maize (*Cheilomenes sexmaculata*, *Coccinella septempunctata* and *Myllocerus dentifer*) agro-ecosystems in New Delhi, India. In both crops, the coleopteran insect community had a similar degree of diversity, indicating a significant role of climate on species diversity (Kalaisekar and Ramamurthy, 2004). The relative occurrence and seasonal abundance of aphidophagous predators (Insecta and Arachnida) determined in alfalfa fields revealed Heteroptera, Dermaptera, Neuroptera, Coleoptera and Diptera as bountiful. Polyphagous predators were much more abundant than aphid specific species. Heteroptera were the most abundant order of insect predators: members of the Nabidae, Anthocoridae and Miridae were very common. Coleoptera were also abundant. Alfalfa, maize and winter cereals shared similar aphid predator groups enabling the movement of predators among crops. The persistence of several predatory groups (Anthocoridae, Nabidae, Staphylinidae, Araneae) during most of the season suggested that alfalfa plays a major role as a reservoir of aphid predators (Pons *et al*., 2005). Tank *et al.* (2007) recorded 9 species of dominant coccinellids, *Cheilomenes sexmaculata*, *Hippodamia variegata, Illeis cincta, Harmonia octomaculata, Coccinella transversalis, Brumoides suturalis, Propylea dissecta, Coccinella septempunctata* and *Anegleis cardoni*, were recorded from Anand, Gujarat. Among these, *Cheilomenes sexmaculata* registered the maximum (3854) number of beetles in a year, followed by *Hippodamia variegata* (550) and *Illeis cincta* (217). Similarly, Rekha *et al.* (2009) reported 9 species of predatory coccinellids, of which 3 common species [*Coccinella transversalis* (Fabricius); *Menochilus sexmaculatus* (Fabricius) and *Brumoides suturalis* (Mulsant)] were found in cereals, pulses and vegetable crops. The diversity of coccinellids was greater in partially weeded plots than in weeded plots, particularly during the succession stage of crop growth and less during early vegetative stage and before harvesting. Rates of community turnover of coccinellids increased in both the weeded and partially weeded canopy with the crop age but at a faster rate in partially weeded canopy. It could be inferred that partially weeded rice or cowpea ecosystem could be a better choice for conserving predatory coccinellid fauna instead of complete weeding, which would play a vital role in the natural suppression of insect pests. In Poland, larvae of four hoverfly species; *Sphaerophoria scripta* (L.), *S. rueppelli* (Wied.), *S. menthastri* (L.) and *Episyrphus balteatus* (Deg.) dominated as aphidophagous predators on maize plants (Krawczyk *et al*., 2011).

2.2 Predation potential of the major aphidophagous guild:

Prey-predation is largely density dependent and ladybirds exhibit definite patterns of predation in response to various prey densities. This can be well- explained in terms of functional and numerical responses (Solomon, 1949). The functional response by ladybirds is a key factor regulating the population dynamics of prey- predator systems describing the rate at which a predator kills its prey at different prey densities and can thus determine the efficiency of a predator in regulating prey population (Omkar and Pervez, 2003; 2004). This is further supported by plotting the number of prey consumed against the number of prey available and analyzing a continuum of patterns delimited into three types (Holling, 1959, 1965). These are linear (Type-I), curvilinear (Type II) and sigmoidal (Type III), which could further be simplified in terms of density-dependence. That is, they result in a constant (I) decreasing (II) and increasing (III) rate of prey killing and yield density- dependent, negatively density-dependent and positively density-dependent prey mortality, respectively.

The entomophagous arthropods that feed aphids can be divided broadly into specialists that include Braconidae and Aphidiinae parasitoids; predatory coccinellids, lacewings and hoverflies (Muller and Godfray, 1999) or generalists that include euryphagous predators like ground beetles and spiders (Lang, 2003). Aphidophagous natural enemies compete for the same prey species. During their foraging activity they frequently encounter hetero-specific aphid predators; such situations can lead to intra-guild predation and may disrupt biological control efforts against aphids where more than one predator species is present; hence, this necessitates carefully choosing a combination of predators for success in biological control of aphids (Hindayana *et al*., 2001).

Helenius (1990) reported that the barriers and egress trenches significantly reduced the pitfall catches of carabids, staphylinids and spiders. The effect on *Coccinella septempunctata* was variable. The peak aphid densities were 11-125 per cent higher in the predator reduction treatments than in the control. The grain yield of oats were reduced by 19-22 per cent in all cases where aphid densities were increased by the manipulations. Relief of predation pressure by generalist epigeal predators is the proposed explanation for the increased *R. padi* densities and subsequently decreased oat yields. Elucidating the dynamics of ladybird beetles in mixed stands of maize, beans and cowpeas to determine their efficacy as the sole control measure for aphids, Nyukuri *et al.* (2012) reported that the predator population was most abundant in the mixed stands of maize and beans (2.33 predators per 30 aphids) as compared to their occurrence in pure stands of cowpeas (0.85 predators per 30 aphids). The genus *Cheilomenes* spp. was the most ubiquitous predator with a mean of 4.00 individuals/30 aphids, while *Hippodamia variegata* was the least abundant predator species with a mean of 0.92 individuals/30 aphids in all the agro-ecosystems. The larvae of *Hippodamia variegata* were the most bio-efficient, consuming 32.44 aphids while their adults were the least bio-efficient, consuming 4.22 individuals for a period of 12 hours. The coccinellids consumed more aphids at higher aphid densities (24.05 Aphids) than at lower aphid densities (9.44 Aphids) over the same period of time. Rainfall and relative humidity had significant ($F=3.675$; $P<0.05$) effects on the abundance of coccinellids. Temperature had significant ($F=3.58$; $P<0.05$) effect on the abundance of coccinellids though at a lower level. Rainfall ($r=-0.162$) and relative humidity ($r=-0.084$) were both inversely correlated with the abundance of coccinellids. On the other hand, temperature was positively correlated ($r=0.159$) with the prevalence of coccinellids indicating that warmer and drier conditions favoured their multiplication.

Ladybirds generally exhibit Type II response operated by satiation and handling time (Omkar and James, 2001; Omkar and Srivastava, 2001; Omkar and Pervez, 2004; Pervez and Omkar, 2003). There are only a few reports of Type I and III responses (Lou, 1987; Hu *et al*., 1989; Haji-Zadeh *et al*., 1994). The multi-colored Asian ladybird, *Harmonia axyridis* has been reported to exhibit all the three responses, *i.e.,* Type I on aphid, *Rhopalosiphum prunifoliae* (Lou, 1987); Type II on aphid *L. erysimi*; and Type III on aphid *Cinara sp*. (Hu *et al*. 1989). Interestingly on a single prey species, (eggs of Monarch butterfly, *Danaus plexippus*), third instar and adults of *H. axyridis* exhibited Type II and Type I response, respectively (Koch *et al*. 2003).

2.3 Efficacy of the aphidophagous guild:

From the literature it has become increasingly clear that coccinellids accept a wide range of food and the larvae eat the same prey as adults. However, they complete larval development and produce viable progeny only if they consume their ‘essential food’ (Hodek, 1973). In contrast, adults can survive on ‘alternative food’ which may consist almost wholly of spores of the lower cryptogams, pollen grains, and plant aphids and varying but little from one genus to another, as observed by Forbes (1876–1883) in his early studies of coccinellid feeding habits (1876–1883).

Common aphidophagous predators found on maize belong to the families Chrysopidae, Coccinellidae, Nabidae and Syrphidae. Some factors affecting the dynamics of the aphid-predator system were investigated in Romania: type of soil, forerunner crops and fertilizers. All combinations providing the best development of plants were favourable both to aphids and predators. The chrysopids constituted 48 per cent of the predator guild. They played the key role in controlling aphids. The main species were *Chrysoperla kolthoffi* and *C. lucasina*. They were components of the common green lacewing complex *Chrysoperla carnea sensu lato*. Adult chrysopid occurrence in maize fields was permanent from mid-June to mid-September, not depending on aphid colony density. The coccinellids constituted 36 per cent of the predator guild. The dominant species was *Coccinella septempunctata*. Ladybirds got into maize from the beginning of July. They established later, only if plants were strongly colonized by aphids (Paulian, 1999).

Pirzada *et al*. (1996) studied the comparative predatory behaviour of the coccinellid, *Menochilus sexamaculatus* [*Cheilomenes sexmaculata*] and observed that the 3rd and 4th instar grubs were more voracious feeders than rest of the instars. The predatory potential of females was significantly higher than males. The laboratory reared beetles were comparatively more voracious feeders than those collected from the field. The mortality of aphid was significantly caused by both the field collected and laboratory reared adult beetles. The mortality of aphids in control was negligible. In laboratory trials, Harjit and Deol (1999) reared *Coccinella spetempunctata* on live *Rhopalosiphum maidis* and observed the feeding capacity at a 24-h interval to make quantitative estimates on the feeding capacity of the beetle. The mean daily consumption of the aphid, *R. maidis* by adults and larvae of *C. septempunctata* was 30.4 and 27.7 at 18.6^{o} C and 71 per cent relative humidity and increased with an increase in the daily temperature. Similarly, Dicko (2000) studied the predation potential of coccinellid, *Cheilomenes propinqua* adults and larvae on the maize leaf aphid, *Rhopalosiphum maidis* infesting *Sorghum bicolor* in the laboratory on arenas made of Petri dishes providing 25, 50, 75, and 100 aphids. The number of attacks by coccinellid adult increased significantly and linearly with increasing prey density. Adult consumption rates were 82-85 per cent in 1997 and 76-97 per cent in 1998. Larvae consumption also increased significantly and linearly with prey density and the consumption rates were 80-93 per cent in 1997 and 85-94 per cent in 1998. Gautam *et al*. (2002) recorded that a single grub of *Coccinella septempunctata* (L)., consumed 281 aphids [mixed population of *Lipaphis erysimi* (Kaltenbach) and *Myzus persicae* (Sulzer)] during its larval period of 9 days under lab conditions. Prey consumption by a grub on a particular day of its age was significantly greater than that on preceding day. Wheat aphid, *Rhopalosiphum maidis* (Fitch) was the most preferred prey of the grubs followed by mustard aphid, *L. erysimi* and safflower aphid, *Uroleucon* sp. In laboratory studies, Singh and Marwaha (2002) evaluated the feeding potential of aphidophagous predators. Adults of *Coccinella septempunctata* consumed a significantly higher number of aphids than larvae of *Syrphus* sp., but less than adults of *Menochilus sexmaculatus*. Adults of coccinellid predators consumed a significantly higher number of maize aphids than predators at immature stages. Grubs of *C. septempunctata* were more active than maggots of *Syrphus*.

The comparative prey consumption and searching efficiency of fourth instar grubs of *Coccinella septempunctata* and *C. transversalis* against three aphid species, *viz*., *Rhopalosiphum maidis*, *Myzus persicae* and *Macrosiphum rosae* were evaluated to assess their efficiency. The larvae of *C. septempunctata* consumed the maximum number (245.60 ± 1.92) of *M. persicae* at a prey density of 800 and minimum number (18.80 ± 0.88) of *R. maidis* at a prey density of 25 in 24 h. Fourth instar *C. transversalis* consumed the maximum number (224.80 ± 1.93) of *M. persicae* at a prey density of 800 and minimum number (17.40 ± 0.58) of *M. rosae* at a prey density of 25 in 24 h. Area of discovery of *C. septempunctata* and *C. transversalis* was maximum at the lowest predator and prey densities of *M. persicae*. It was the minimum in the case of *C. septempunctata* and *C. transversalis* at highest predator and prey densities (800) of *R. maidis* and *M. rosae*, respectively. Prey consumption by both coccinellids increased, but their searching efficiency decreased with increase of either prey or predator density. The predatory potential and searching efficiency of *C. septempunctata* was relatively higher than that of *C. transversalis* (Omkar and Srivastava, 2003). On the basis of overall performance of *Cheilomenes sexmaculata* (Fab.), Omkar and Bind (2004) recorded the order of suitability of prey species as *A. craccivora* > *A. gossypii* > *R. maidis* > *M. persicae* > *U. compositate* > *L. erysimi* > *A. nerii*. Similarly, Lucas *et al.* (2004) observed that for *Coccinella septempunctata* (L.) and *Hormonia axyridis* (Pallas) the total number of prey killed (total prey species pooled) and the total biomass were significantly higher when both prey (*Aphis pomi* and *Choristoneura rosaceana*) were present than in single prey treatment. The voracity of *C. septempunctata* on *C. rosaceana* larvae was not affected by adding the aphid, *A. pomi*; whereas that of *H. axyridis* declined; the voracity of both predators on *A. pomi* increased when *C. rosaceane* larvae were added. The preference for the aphids over *C. rosaceana* was confirmed for both coccinellid species. Mandal and Patnaik (2006) found that *Coccinella septempunctata* preyed on the highest number of aphids with each individual consuming 1066.10 *Lipaphis erysimi*, 950.76 *Myzus persicae* and 873.16 *Brevicoryne brassicae* in its life time. Similarly, predation by *Coccinella repanda* [*Coccinella transversalis*], *Cheilomenes sexmaculata* and *Micraspis discolor* was 1023.69, 768.84 and 595.13 *L. erysimi*, 932.81, 527.85 and 516.32 *Myzus presicae,* and 822.96, 478.52 and 451.83 *B. brassicae,* respectively.

Park and Obrycki (2004) opined that prey-predator interactions are spatially and temporally dynamic and influenced by environmental factors. Geostatistical analysis showed that both corn leaf aphid and lady beetle populations were aggregated during the peak population period and randomly distributed early and late in the season. The results also showed that none of the environmental factors were significantly correlated with corn leaf aphid and lady beetle distributions. Evaluating short term effects of *Coccinella septempunctata* preying on *Rhopalosiphum padi* living on maize producing Cry34+Cry35 toxins during pollination, Takacs *et al*. (2010) revealed that in the treatment where no pollen or aphid food source was offered all individuals died as first instar larvae on both maize types tested (isoline and those producing the cry toxins). Where only maize pollen was provided, 10 per cent molted to second instar larval stage without growth and then all individuals died. When newly hatched second instar larvae were given similar aphid prey, the survival and development of second instar grub did not significantly differ on isoline and maize plants producing Cry3 toxins.

Pandi *et al.* (2012) conducted laboratory studies to find out the consumption rate and biology of coccinellid predator *Cheilomenes sexmaculata* (Fabricius), on aphid hosts, *viz.*, *Aphis craccivora* Koch, *Aphis gossypii* Glover, *Rhopalosiphum maidis* (Fitch) and *Lipaphis erysimi* (Kaltenbach). The potential hosts, beginning with the best may be arranged as *A. craccivora*, *A. gossypii*, *R. maidis*, and *L. erysimi* in descending order. The 4^{th} instar grubs consumed significantly more aphids when compared to 1^{st}, 2^{nd} and 3^{rd} instars. The per day predation rate (number of aphids) by female beetle on *A. craccivora* was 37.2 ± 3.32, followed by *A. gossypii* (35.2 ± 2.22), *R. maidis* (31.6 ± 2.44), and *L. erysimi* (23 ± 0.94). Males could feed only 35.8 ± 2.67 of *A. craccivora*, followed by 30.8 ± 1.98 of *A. gossypii*, 27.8 ± 4.28 of *R. maidis*, and 20.8 ± 1.15 of *L. erysimi*. Male and female longevity was lowest (26.8 ± 1.71 and 34.6 ± 1.36 days) on *L. erysimi* and longest (41.6 ± 0.98 and 48.2 ± 2.67 days) on *A. craccivora*. The decreasing order of development rate observed of *C. sexmaculata* was *A. craccivora*> *A. gossypii*> *R. maidis*> *L. erysimi*.

3. MATERIALS AND METHODS

The present investigation entitled, "*Diversity of aphidophagous natural enemy guild in maize*" was carried out during summer (*zaid*) and *kharif* seasons of 2013 at the Instructional Farm, Rajasthan College of Agriculture, Udaipur. The details of the materials used methodology adopted have been mentioned below

3.1 Location of the experimental site

The experimental site was located at the Instructional Farm, Rajasthan College of Agriculture, Udaipur. Geographically Udaipur is situated at 75.4^0 E Latitude and 23.4^0 N Longitude at an elevation of 582.17 MSL in the sub-humid southern region of Rajasthan.

3.2 Climatic conditions of the location

The zone has a typical sub-tropical climatic condition characterized by moderate winter and hot summer associated with high humidity especially during months of July to September. The average rainfall of this tract ranges between 450-650mm, contributed by South-West monsoon from July to September with occasional rains during the winter season. During summers, the atmospheric temperature may go as high as 45.5^oC, while in winters, it may fall as low as 3.5^oC occasionally.

3.3 Field preparation and sowing of maize crop

One deep ploughing and two cross harrowing were done to improve the field condition. Sowing of summer crop of maize (Pratap Makka 5) was done on 3^{th} April, 2013 and that of the *kharif* crop on 9^{th} August, 2013. Phosphatic fertilizer as basal dose of 40 kg/ha while N was applied at 80 kg/ha in two split doses. The summer crop was cultivated providing timely irrigations, while the *kharif* crop was rainfed. The other agronomic practices such as thinning, hoeing and weeding were performed as and when needed following the package of practices for cultivation of maize.

3.4 Study plot and crop details

The aphidophagous natural enemies were collected along with their aphid prey from maize (Pratap Makka 5) fields during summer and *kharif* seasons in 2013.

Collections were made twice a week during the aphid infestation period beginning at tassel initiation stage. The aphidophagous natural enemy diversity was recorded from treated (Imidacloprid 600 FS @ 4.8g a.i./kg seed or 6 ml/kg of seed), untreated as well as sole maize and maize with cowpea intercropped (in a ratio of 1:1) fields.

3.5 Arthropod monitoring

a) <u>Pest aphids count</u>

Aphids collected from the fields was segregated on morphological basis into different species and later identified. The population count was made from 5 randomly-selected maize plants from each plot, selecting the top 20cm meristematic region where aphids usually congregate and feed. The number of winged and wingless adults, nymphs and mummies (mummified aphids hosting parasitoids) for each aphid species was accounted for during observation.

b) <u>Aphidophagous natural enemy count</u>

i. Parasitoid count

The aphid parasitoids were estimated from the count of aphid mummies per plant as per methodology mentioned above in 3.5 (a).

ii. Specific and generalist predator count

The predator abundance was recorded as per stage of development:

a) First, larvae of lacewings, coccinellids and hoverflies were counted on the same shoots used to count the aphids.

b) Second, adult aerial predators, mainly coccinellids, were recorded visually by walking in between the central rows of maize in each replicate and expressing the population on a per plant basis from the top 20cm shoot.

c) Third, the ground-dwelling predators were collected using pitfall traps. Three pitfall traps (ca 500ml glass jar with ethylene glycol) were positioned diagonally within each replicate. The traps were dug down to ground level. Transparent plastic covers were be placed above the traps to prevent flooding by rain during the *kharif* season.

d) Aphids and aerial predator transects were inspected between 07:00 and 08:00 a. m.

e) Ambient atmospheric temperature and percentage of relative humidity was measured prior to sampling. Sampling was carried out as soon as aphid infestation began.

f) The entire arthropod community was determined to species, wherever possible, in addition, the predators were classified into specific or generalist predators.

g) Linear relationship between aphids and the aphidophagous predators; aphids and the abiotic factors of the environment (mean atmospheric temperature and mean relative humidity) was established. The correlation coefficient values were tested for their significance with Student's (t)-test.

3.6 Efficacy of aphidophagous natural enemy guild

The field cage experiment to test the effect of natural enemy guild on aphid population was carried out at the Instructional Agronomy Farm, RCA Udaipur on summer (*zaid*) and *kharif* season maize. In each selected field the following treatments were taken that were replicated 6 times:

(1) An open control (O)

(2) Ground-dwelling predator exclusion (G)

(3) Aerial predator and parasitoid exclusion (F) and

(4) Total exclusion (T), which was the combination of treatments (2) & (3), *i.e.*, G and F.

Metallic barriers to exclude ground-dwelling predators (*e.g.*, spiders, carabids, staphylinids) were placed. The barriers were circular, 0.5 m in diameter, dug into the soil. Ground-dwelling predators captured in these traps were counted and removed. Aerial aphid predators and parasitoids were excluded by setting wire cages over the plants. The cages were of a mesh size of 8mm allowing airflow to avoid changes in microclimate conditions (Schmidt *et al.*, 2003) and were covered with sticky glue to intercept or hinder aerial predators and parasitoids from entering. The bottom edge of the cages was left without glue to permit ground-dwelling predators access. With a view to maintain a uniform initial population, at initiation of tassel in the summer crop of maize, aphid abundance was recorded on 20cm length of top shoot and 1-day before caging, *ca* 500 aphids were left on the shoot removing excess aphids, wherever present, with the help of a camel hair brush.

3.7 Culture of coccinellids in the laboratory and predation potential trial

a) The adult coccinellids were field collected from the untreated crop fields of the Instructional Farm of the College and brought to the laboratory to maintain a stock culture under ambient conditions of temperature and humidity. The mean atmospheric temperature ranged from 23 to 34^{o} C and at 51 to 74 per cent relative humidity. Mating pairs were kept in glass jars (500ml capacity) covered with muslin cloth that was fastened with rubber bands. The eggs laid on maize leaves (20) were placed into fresh glass jars till the first instar grubs emergence, which were then provisioned with fresh maize aphids daily as food.

b) To evaluate the predation potential of coccinellid grubs at different aphid densities (25, 50, 75, 100, 125 and 150), four healthy second instar grubs were separated with the help of a camel hair brush after the first moult and transferred into individual glass jars of 500ml capacity covered with a muslin cloth held together by rubber bands, considered as 4 replicates. Observations on the consumption of aphids were recorded in each replicate under the different treatments after 24h. The experiment was continued for 5 days and left over aphids and dried maize shoots were replaced daily with fresh ones to avoid contamination and consequent mortality.

c) To evaluate the predation potential of adult beetles, *Coccinella septempunctata* (Linneaus), *Cheilomenes sexmaculata* (Fabricius) and *Illeis cincta* (Fabricius) were field collected from the untreated maize crop and reared on the maize aphid (dominant being *R. maidis*) as prey. Having starved the adult coccinellids for 6h they were individually transferred to glass jars with different aphid prey densities on fresh maize leaves replicated 4 times. Observations on consumption of aphids were recorded in each replicate under the different treatments after 24h. The evaluation was continued for 5 days replacing left over aphids and dried maize shoots daily with fresh ones to avoid contamination and consequent mortality.

3.8 Mathematical and statistical analyses

The following mathematical analysis was made towards estimating the species richness of aphidophagous natural enemies and their diversity indices:

Mean density (MD)

$$\text{Mean density (\%)} = \frac{Xi}{N} \times 100$$

Where, Xi = Numbers of insects; N = Total numbers of plants sampled.

Relative density (RD)

$$\text{RD\%} = \frac{\text{Number of individual of one species}}{\text{Total number of individual of all species}} \times 100$$

Shannon –Weiner diversity index (H')

Shannon – Weiner diversity index (H') = $-\Sigma$ pi ln pi

Where, Pi = The decimal fraction of individuals belonging to i^{th} species

Predation Efficiency

The predation efficiency of dominant aphidophaous coccinellids was evaluated through the determination of the voracity following the model of Soares *et al.* (2003)

Vo = (A − a 24) ra 24

Where, Vo = number of aphids eaten; A = number of aphids available

a 24 = number of aphids alive after 24 h and

ra 24 = ratio of aphids found alive after 24 h in the absence of predators.

The data obtained were subjected to Analysis of Variance and other suitable statistical procedures to analyze the results of the investigations conducted.

4. RESULTS

The seasonal incidence of the maize aphid along with its common natural enemies under the influence of abiotic factors of the environment has been presented in tables and as graphs. The qualitative and quantitative abundance of the aphidophagous guild, their predation efficacy in the field under different exclusion treatments and in the laboratory at different prey densities were recorded using standard sampling methods and have been presented here in tables, figures and text form.

4.1 Diversity of aphids and their natural enemies:

The aphids collected from maize were *Rhopalosiphum maidis* (Fitch) and those from cowpea were *Aphis craccivora* (Koch) [Aphididae: Hemiptera]. The associated natural enemies of aphids on maize included coccinellids [*Coccinella septempunctata* Linneaus,*Cheilomenes sexmaculata* (Fabricius), *Brumoides suturalis* (Fabricius), and *Illeis cincta* (Fabricius) Coccinellidae: Coleoptera]; the big-eyed bug [*Geocoris* sp., Lygaeidae: Hemiptera]; the rove beetle [*Paederus fuscipes* Curtis, Staphylinidae: Coleoptera]; and syrphid flies [major being *Ischiodon* sp., Syrphidae: Diptera].

The seasonal incidence of the maize aphid during the summer season and *kharif* season, as presented in Tables (1) & (2) respectively, indicate that the seasonal mean aphid abundance on maize during *kharif* was relatively more than that during summer (*zaid*) season. The mean population ranged from 237.00 aphids per plant to 373.05 aphids per plant with the seasonal mean being 291.26 aphids per plant on the summer crop (Table: 1). Likewise, the mean population ranged from 269.85 aphids per plant to 520.12 aphids per plant with the seasonal mean being 369.09 aphids per plant on the *kharif* season crop (Table: 2). During summer season, the mean atmospheric temperature had a mild negative correlation with the aphid population, while the mean relative humidity evinced a mild positive correlation with the aphid population though the r-values were non-significant. During *kharif* season, the mean atmospheric temperature had a significant positive correlation with the aphid population (r = 0.65); whereas, the mean relative humidity showed a mild positive influence on aphid population. It could be inferred that an increase in the mean atmospheric temperature during *zaid* (summer) caused a reduction in aphid numbers, while during *kharif* it caused a significant increase in aphid numbers.

The associated aphidophagous natural enemies were relatively a little more during the *kharif* season as compared to that during the *zaid* (summer) season. The mean adult coccinellid population (inclusive of 4 species) ranged from 5.14 to 11.77 per plant with the seasonal mean of 7.78 beetles per plant on the summer crop; while the corresponding values for *kharif* crop were 6.40 to 10.58 per plant with the seasonal mean of 8.56 beetles per plant. The lygaeid bug, *Geocoris* was in significant numbers with the seasonal mean of 3.60 and 3.76 bugs per plant during *zaid* and *kharif* seasons, respectively. The staphylinids had a seasonal mean population of 2.87 and 3.14 per plant, while the syrphids were 1.89 and 2.41 per plant during the *zaid* and *kharif* seasons, respectively. It could be observed the populations of the aphidophagous natural enemies were more during *kharif* than in *zaid*, possibly being favoured by the humid conditions. The population of coccinellids showed much variation, while that of *Geocoris*, staphylinids and syrphids did not show much variation within the seasons (Tables 1 & 2). The population trend of the maize aphid and the associated natural enemies has been depicted in the Figures (1) & (2), based on log population of both during *zaid* and *kharif* seasons, respectively.

Among the aphidophagous natural enemy guild recorded during both the *zaid* and *kharif* seasons, coccinellids dominated with 48.23 and 47.91 per cent relative density, respectively; followed by the big-eyed bug, *Geocoris* with a RD value of 22.30 and 21.03 per cent (Table: 3). However, the Shanon diversity index values did not differ for the two seasons (1.24 and 1.25 for *zaid* and *kharif*, respectively).

4.2 Efficacy of the aphidophagous guild:

The efficacy of the aphidophagous guild was evaluated in a field experiment wherein known numbers of aphids were caged or excluded from predation by aerial predators, ground dwelling predators, both and an uncaged or open control. It was notable that excluding aerial predators enabled ground dwelling predators to access the aphids, while exclusion of ground dwelling predators enabled the aerial predators to access the apids. Likewise, exclusion of both types of predators resulted in exponential population growth of the aphids. From the Table (4) and Figure (3) it becomes clear that aerial predators contributed significantly more towards aphid predation than the ground dwelling predators, as shown by the decrease in aphid numbers from 500 to 4.17 at five days after treatment; whereas, ground dwelling predators caused a decrease in aphid numbers from 500 to 56.67 at five day after treatment. However, in the no exclusion treatment, where access to aphid prey was provided to both types of predators (aerial and ground dwelling) the decrease in aphid numbers was the maximum being 3.00 at four days after treatment and zero at five days after treatment. It is therefore conspicuous that the aphidophagous predators play a major role in maintaining the aphid populations below those causing economic damage. Nevertheless, one can observe these predators actively foraging except on rainy days while in the field.

A perusal of the Table (5) explains the feeding propensity of these aphidophagous predators under different exclusion treatments. Aphid consumption (%) was maximum (100 per cent) under no exclusion treatment (control) closely followed by when ground dwelling predators were excluded (99.75%); whereas, it was 89.38 per cent when aerial predators were excluded. The treatment of total exclusion (excluding both aerial and ground dwelling predators), in contrast, showed a cumulative increase in the aphid population over the initial population of 500 aphids per plant depicting an increase from 34.00 to 62.87 per cent (Table: 4) (Fig. 3).

4.3 Predation potential of the major aphidophagous guild

The predation potential of the dominant aphidophagous guild comprising the adult and grubs of coccinellids of three species was evaluated by their feeding behavior at different aphid prey densities (25, 50, 75, 100, 125 and 150 per beetle). From the Table (6) it can be inferred that the grubs of *Coccinella septempunctata* Linneaus could feed significantly more aphids at the different densities evaluated followed by *Illeis cincta* (Fabricius) and *Cheilomenes sexmaculata* (Fabricius). All the three coccinellid grubs increasingly and significantly consumed more aphids at aphid densities of 25, 50 and 75, but at higher aphid densities (100, 125 and 150) the consumption rate declined. The prey consumption on a number basis differed significantly at different densities with

Coccinella septempunctata Linneaus feeding 20.55 to 24.70; *Illeis cincta* (Fabricius) feeding 19.70 to 23.00 and *Cheilomenes sexmaculata* (Fabricius) feeding 18.95 to 21.15 aphids in 24 hours with the maximum being when 75 aphids as prey were provided. From the Figure (4) on feeding behavior it becomes clear that an increase in prey density sharply decreased the per cent feeding by the grubs. Notwithstanding the fact that aphidophagous coccinellids prefer to feed on aphids, they are specific predators of aphids at low densities between 25 and 50. However, this gives an indication that field releases of coccinellid grubs might prove useful at higher aphid densities considering the feeding ability of a single coccinellid grub.

A perusal of the Table (7) indicates that the adult coccinellids showed little difference in their feeding potential. Similar to the behavior of grubs, all the three adult coccinellids consumed more aphids with increase in the prey density up to 75 aphids per adult; thereafter their feeding capacity declined. The prey consumption on a number basis did not differ much at different densities with *Coccinella septempunctata* Linneaus feeding 18.70 to 22.55; *Illeis cincta* (Fabricius) feeding 17.80 to 20.95 and *Cheilomenes sexmaculata* (Fabricius) feeding 15.95 to 19.35 aphids in 24 hours with the maximum being when 75 aphids as prey were provided. Similar to the feeding behavior of grubs, from the Figure (5) it can be observed that an increase in prey density sharply decreased the per cent feeding.

5. DISCUSSION

Literature abounds in laboratory based predator-prey feeding trials; however, quite a few field trials have been conducted that were consulted and the results obtained in our trials have been discussed in the light of their work.

The aphids recorded on maize were *Rhopalosiphum maidis* (Fitch) and those on cowpea were *Aphis craccivora* (Koch) [Aphididae: Hemiptera]. The aphidophagous guild comprised coccinellids [*Coccinella septempuctata* Linneaus, *Cheilomenes sexmaculata* (Fabricius), *Brumoides suturalis* (Fabricius), and *Illeis cincta* (Fabricius), Coccinellidae: Coleoptera]; the big-eyed bug [*Geocoris* sp., Lygaeidae: Hemiptera]; the rove beetle [*Paederus fuscipes* Curtis, Staphylinidae: Coleoptera]; and syrphid flies [major being *Ischiodon* sp., Syrphidae: Diptera]. Earlier workers have also reported *Rhopalosiphum maidis* (Fitch) as the major aphid pest on maize; however, *Rhopalosiphum padi*, *Sitobion avenae* and *Metopolophium dirhodum* were also recorded in addition (Coderre and Tourneur, 1988; Coderre *et al*., 1989; Plewa and Pankanin-Franczyk, 1989). In Egypt, Darwish and Ali (2001) reported *Schizaphis graminum* and *Rhopalosiphum maidis* on maize during 1988 and 1989.

The seasonal mean aphid abundance on maize during *kharif* was relatively more than that during summer (*zaid*) season. The seasonal mean population was 291.26 aphids per plant on the summer crop and 369.09 aphids per plant on the *kharif* season crop. The mean atmospheric temperature had a mild negative correlation with the aphid population, while the mean relative humidity evinced a mild positive correlation in summer. During *kharif* season, the mean atmospheric temperature had a significant positive correlation with the aphid population; whereas, the mean relative humidity showed a mild positive influence on aphid population. It could be inferred that an increase in the mean atmospheric temperature during *zaid* (summer) caused a reduction in aphid numbers, while during *kharif* it caused a significant increase in aphid numbers.

Earlier, Coderre and Tourneur (1988) observed that the 2 species of *Rhopalosiphum* showed a bimodal seasonal distribution, with a decrease in abundance at the end of July. Climatic factors and emigration could not explain this decrease, but was probably related to diminished plant nutritional quality and an increase in predation. Darwish and Ali (2001) observed that aphids occurred at the beginning of August, and reached their maximum abundance (406 and 518 per plant) in the 4th week of August, when the plants were in their reproductive stage. Aphid populations began to decrease from the 3rd week of September, to reach their lowest levels in mid-October, when the plants were mature.

In the present investigation, natural enemies were relatively more during the *kharif* season as compared to that during the *zaid* (summer) season possibly on account of being favoured by the humid conditions. The mean adult coccinellid population had a seasonal mean of 7.78 beetles per plant on the summer crop, while for the *kharif* crop the seasonal mean was 8.56 beetles per plant. The seasonal mean populations of *Geocoris* species were 3.60 and 3.76 bugs per plant during *zaid* and *kharif* seasons, respectively. The staphylinids had a seasonal mean population of 2.87 and 3.14 per plant, while the syrphids were 1.89 and 2.41 per plant during the *zaid* and *kharif* seasons, respectively. The population of coccinellids showed much variation, while that of *Geocoris*, staphylinids and syrphids did not show much variation within the seasons. Among the aphidophagous natural enemy guild recorded during both the *zaid* and *kharif* seasons, coccinellids dominated, followed by the big-eyed bug, *Geocoris*; however, the Shanon diversity index values did not differ for the two seasons.

Voicu (1989) observed *Rhopalosiphum maidis* on maize from 3 regions of Romania to be controlled by 23 species of predatory insects, including 2 anthocorids, 3 nabids, 2 chrysopids, a cantharid, 2 malachiids, 10 coccinellids and 3 syrphids. Plewa and Pankanin-Franczyk (1989) found coccinellids (4 species) and chrysopids (3 species) as the most abundant predators, followed by syrphids and nabids, and 6 species of aphidiid [Braconidae] parasitoids. Coderre *et al*. (1989) reported that among predators, the coccinellids, *Coleomegilla maculata lengi* and *Hippodamia tredecimpunctata* were significantly more abundant in the monoculture than in the maize intercropped with beans, but *Coccinella septempunctata* and spiders were not. However, Asin and Pons (1998) observed that though coccinellids (*Coccinella septempunctata*, *Adonia variegata*, *Propylaea quatuordecimpunctata*) were the most common aphid-specific predators, polyphagous predators were more abundant, mainly anthocorids (*Orius* spp.), carabids (*Demetrias atricapillus*, *Harpalus rufipes*, *Bembidion* spp., *Poecillus cupreus*, *Agonum dorsale*), dermapterans (*Labidura riparia*, *Forficula auricularia*), nabids (*Nabis provencalis*) and spiders. According to Paulian (1999) the relatively more common aphidophagous predators on maize belonged to the insect families Chrysopidae, Coccinellidae, Nabidae and Syrphidae; types of soil, forerunner crops and fertilizers affected the dynamics of the aphid-predator system in Romania. Similar to our observation, Jagmohan Singh and Brar (2004) reported that among coccinellids, *C. septempunctata*, *C. transversalis*, *Brumoides suturalis* and *Cheilomenes sexmaculata* are the most widespread. Thus, it can be inferred that coccinellids happen to be the most dominant aphidophagous predator of maize aphids as recorded during the present investigation; however, the coccinellid, *Illeis cincta* was equally abundant in our trials that earlier workers have not reported, which could be specific to our climatic conditions.

Exclusion of both types of predators resulted in exponential population growth of the aphids. The treatment of total exclusion, showed a cumulative increase in the aphid population over the initial population of 500 aphids per plant. Aerial predators contributed significantly more towards aphid predation than the ground dwelling predators, as shown by relatively more decrease in aphid numbers. In the no exclusion treatment, where access to aphid prey was provided to both types of predators (aerial and ground dwelling) the decrease in aphid numbers was the maximum. It becomes increasingly clear that the aphidophagous predators play a major role in maintaining the aphid populations below those causing economic damage. Aphid consumption was significantly maximum (100 per cent) under no exclusion treatment (control) closely followed by when ground dwelling predators were excluded, i.e., consumption by aerial predators (99.75%); whereas, it was 89.38 per cent when aerial predators were excluded, i.e., consumption by ground dwelling predators.

In earlier studies on the manipulation of densities of generalist epigeal predators by vertical barriers or ingress and egress trenches, Helenius (1990) reported that the barriers and egress trenches significantly reduced the pitfall catches of carabids, staphylinids and spiders. The effect on *Coccinella septempunctata* was variable. The peak aphid densities were 11-125 per cent higher in the predator reduction treatments than in the controls. The grain yields of oats were reduced by 19-22 per cent in all cases where aphid densities were increased by the manipulations. Relief of predation pressure by generalist epigeal predators is the proposed explanation for the increased *R. padi* densities and subsequently decreased oat yields.

Our evaluation of predation potential of the dominant aphidophagous guild comprising the grubs and adult coccinellids of three species evinced that *Coccinella septempunctata* consumed relatively more aphids at the different densities followed by *Illeis cincta* and *Cheilomenes sexmaculata*. It was notable that all the three coccinellids consumed increasingly more aphids at lower aphid densities (25 to 75); thereafter, at higher aphid densities (100 to 150) aphid consumption decreased indicating their better efficiency at lower densities. The prey consumption on a number basis differed significantly at the lower prey densities (25 to 75) for the three coccinellids being the maximum when 75 aphids were provided. On the basis of feeding behavior, an increase in prey density sharply decreased the per cent feeding.

Earlier, Harjit and Deol (1999) observed the mean daily consumption of the aphid, *R. maidis* by adults and larvae of *C. septempunctata* to be 30.4 and 27.7 at 18.6^{o} C and 71 per cent relative humidity that increased with an increase in the daily temperature. Contrary to our findings that coccinellids were more efficient at lower aphid densities, Dicko (2000) reported that the number of attacks by coccinellid adults increased significantly and linearly with increasing prey density. Adult consumption rates were 82-85 per cent in 1997 and 76-97 per cent in 1998. Larvae consumption also increased significantly and linearly with prey density and the consumption rates were 80-93 per cent in 1997 and 85-94 per cent in 1998. Singh and Marwaha (2002) reported that adults of *C. septempunctata* consumed a significantly higher number of aphids than larvae of *Syrphus* sp., but less than adults of *M. sexmaculata*. Adults consumed a significantly higher number of maize aphids than immature stages. Grubs of *C. septempunctata* were more active than maggots of *Syrphus*.

6. SUMMARY

The aphids recorded on maize and cowpea were *Rhopalosiphum maidis* (Fitch) and *Aphis craccivora* (Koch), respectively. The aphid feeding guild comprised the dominant coccinellids (*Coccinella septempunctata* Linneaus, *Cheilomenes sexmaculata* (Fabricius) *Brumoides suturalis* (Fabricius) and *Illeis cincta* (Fabricius); followed by the lygaeid big-eyed bug (*Geocoris* sp.,); rove beetle (*Paederus fuscipes* Curtis) and syrphid flies (*Ischiodon* sp.,). The seasonal mean population of aphids on *kharif* maize was relatively higher as compared to that on summer (*zaid*) maize crop. The mean atmospheric temperature had a significant positive correlation with the aphid population during *kharif* season; whereas, the population of aphid showed a mild positive influence with mean relative humidity. Similarly, the population of natural enemies was relatively more during *kharif* season than that during summer (*zaid*) season.

Among the aphidophagous natural enemy guild the coccinellids dominated followed by the big-eyed bug, *Geocoris* during both seasons. The efficacy of aphidophagous guild, evaluated in the field, showed that aerial predators contributed significantly more towards aphid predation as compared to ground dwelling predators. A cumulative increase in the aphid population over the initial population of 500 aphids per plant was noted in total exclusion. Aerial predators consumed more aphids than the ground dwelling predators. In the treatment where access to aphid prey was provided to both types of predators (aerial and ground dwelling) the decrease in aphid numbers was maximum. It becomes increasingly clear that the aphidophagous predators play a major role in maintaining the aphid populations below those causing economic damage. Laboratory evaluation of feeding behavior of grubs and adults of the three species of coccinellids showed that *Coccinella septempunctata* Linneaus consumed relatively more aphids at different prey densities followed by *Illeis cincta* (Fabricius) and *Cheilomenes sexmaculata* (Fabricius). The consumption rate per day was the maximum at a prey density of 75 aphids for all the three species, both as grubs and adult beetles. Likewise, an increase in prey density showed a gradual to sharp decline in the percentage consumption of aphids.

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