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Biological Control of Insect and Fungal Pests by Predominant Coccinellidae Beetles-A Review

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A B S T R A C T

Ladybird beetles (Coleoptera: Coccinellidae) are a variety of creatures that can be found in a wide range of terrestrial ecosystems. They are members of the Coleoptera order, Polyphaga suborder, Cucujoidea superfamily, and Coccinellidae family. The majority of the coccinellids are predatory in nature and feeds on a variety of pests like aphids, thrips, small larvae, mites, fungus, etc., and thus have huge potential for managing a wide range of pests of economically significant crops. Both the adult and larval stages are predacious in nature and feed on different kinds of pests. Since they are the natural answer to pest control and are far more efficient than hazardous chemicals, their existence in agroecosystems aids in lowering the use of dangerous chemical pesticides. Coccinellids are multivoltine i.e., producing many generations in a year. The life cycle of coccinellids has four developmental stages: eggs, larva, pupa, and adult. By utilizing various tactics, the efficacy of coccinellids as biological control agents can be increased. Such as spraying nutrients like sucrose on crops to enhance the reproductive rate of coccinellids. Numerous insect and fungal pests disrupt ecosystems in horticulture and agriculture around the world; these pests are naturally managed by biocontrol agents. In the present review the role of coccinellids as biological control agents of insects and fungal pests has been analyzed.

Introduction

The ladybird beetles are the members of class Insecta and belong to the family Coccinellidae. Coccinellids are ecologically diverse and inhabit all terrestrial environments. They are members of the superfamily Cucujoidea, family Coccinellidae, suborder Polyphaga, and order Coleoptera. Coccinellidae is a family of about 6,000 known species in 360 genera (Vandenberg, 2002; Slipinski, 2007; Hodek *et al.*, 2012). The family from the Indian subcontinent continues to lack appropriate documentation despite having 414 recognized species, including about 23 from the Union territory of Jammu and Kashmir (Canepari, 1997; Poorani, 2002, 2012; Poorani and Thangjam, 2019). Coccinellid beetles are of great importance to the agroecosystem as they prey upon many harmful insect pests (Agarwala *et al.,* 1988).

Both larvae and adults are predacious in nature and feed on different kinds of pests. Most coccinellids are entomophagous and feed on insect pests like aphids, thrips, and mites, but some are mycophagous and phytophagous. Generally, coccinellid beetles are multivoltine (having many generations in a year). The four developmental stages that ladybird beetles go through are the embryonic, larval, pupal, and adult stages. Before becoming adults, the larvae go through four instar stages. Temperature, relative humidity, rainfall, and the availability of food all have an impact on how long coccinellids live. Usually, it takes 3-4 weeks to complete the life cycle but during winter it may take 6 weeks.

Biological control by predominant coccinellids

According to DeBach (1964), biological control is the process by which infections, parasites, or predators maintain the average population density of other organisms lower than it would be in the absence of those agents. Biological control is an environmentally friendly method of lowering insect populations below economic threshold levels by utilizing natural pest enemies. Biological control poses no risk of contamination of the environment or harm to the health of humans or other domestic animals. The most effective natural pest predator must have the following characteristics: a high degree of host/prey specificity, a high population growth capacity relative to its host/prey, a high seeking capability, especially at low concentrations of host/prey, adaptability to changing environmental physical conditions, Seasonal synchrony with its host or prey, the capacity to persist without the host or prey, and the flexibility to alter its course of action as necessary. Coccinellids have all the aforementioned features and thus play a significant role in controlling pests. Of many horticultural and agricultural crops, resulting in a significant reduction in economic loss, natural pest control agents are far more effective than toxic chemicals.

Coccinellids feeding on insect pests

Since most coccinellid beetles are beneficial insect pest predators, they play an important role in developing biological control strategies. The Ladybird beetles are beneficial in the management of crop pests like aphids, whiteflies, mites, etc. but specific beetle feeds on a particular aphid. The prey of coccinellids is classified into four groups: essential, alternative, rejected, and toxic (Majerus, 1994). The coccinellid beetles prefer essential prey because when they feed on this category of prey they perform better in terms of egg maturation, oviposition, and development. Alternative and toxic pests are taken at a lower rate. (Hodek, 1973; Majerus, 1994). Ladybirds have been utilized as biological pest control agents for a long time (Majerus, 1994). *Rodolia cardinalis*, an Australian vedalia ladybird, was released in 1888 to eliminate cushiony scale insects *Icerya purchase*, which were wreaking havoc on the California citrus sector (Majerus, 1994). After being deployed as a traditional biological control agent, this ladybird became established and drastically reduced the number of scale insects. (Fig. 2).

This was the beginning of biological control as we know it today. Similarly, due to its rapid development rate, high reproductive potential, high prey consumption rate, and simplicity of rearing, *Cryptolaemus montrouzieri* Mulsant (Coleoptera: Coccinellidae) is one of the biological control agents that is most commonly used. Recently it was used to control Hibiscus Mealybug in the Caribbean and South America (Kairo *et al.,* 2000). It was widely employed in coffee plantations, fruit orchards, and vineyards in India (Mani, 1988). Adult coccinellid beetles were released through the augmentation method to control the outbreak population of eucalyptus leaf beetle *Chrysophtharta bimaculata* in *Eucalyptus nitens* plantations (Mensah *et al.,* 1994). The findings of this study imply that *C. bimaculata* may be biologically controlled by the inundative release of laboratory-reared coccinellids, although this strategy could only be financially feasible in limited environmentally sensitive areas. In the USA, *Harmonia axyridis* Pallas, one of the most invasive ladybird beetles on the planet, was originally utilized in 1916 as a traditional biological control agent. However, by the late 1980s, it had come to be recognized as an invasive foreign species (Koch *et al.,* 2003). The coccinellid beetle *Brumoides suturalis* (Fabricius) is an important predator that feeds on white-backed plant hopper which infects Rice crops of India. This plant hopper created havoc in different parts of Rice fields in India and was then successfully controlled by *Brumoides suturalis* (Fabricius) (Garg and Sethi, 1983). Abraham and Mathews (1976) study the biology and predatory potential of *Coccinella arcuata* which is a predator of brown plant hopper *Nilaparvata lugens* present in rice crops. In this study, they found that *Coccinella arcuata* is an effective biological control agent owing to its high efficiency against this plant hopper. *Diomus terminates*, a predator of *Sipha flava* which is found foraging on grasses is a good biocontrol agent for this pest in Brazil (Auad *et al.,* 2013). In several South American countries, it was discovered that the ladybird beetle *Eriopus connexa* (Germar) fed on various insect pests of maize and sorghum; as a result, mass raising of this insect became crucial for the biological control program. *Eriopus connexa* has a polyphagous feeding habit and has a good adaptation power thus having a potential for controlling corn and sugarcane pests (Silva *et al.,* 2013). Studies of numerous alien aphid species that were established in North America are part of extensive examinations of Coccinellidae-aphid pest interactions that began in the early 1950s (reviewed by Hagen and van den Bosch, 1968; van Emden, 1972). Following an unintentional introduction into California in the 1950s, the spotted alfalfa aphid, *Therioaphis trifolii* (Monell) (Hemiptera: Aphididae), was attacked by numerous naturally occurring Hippodamia species, most notably *Hippodamia convergens.* (Guerin) (Coleoptera: Coccinellidae) (Hagen, 1974). Although predation alone was unable to sufficiently suppress aphids, subsequent studies showed the importance of predation when complemented by the use of selective insecticides for the suppression of *T. trifolii* (Stern and van den Bosch, 1959). The predatory capacity of coccinellids, specifically *Chelomenes vicina, Diomers flavipes, Diomers hottentota,* and *Coccinella septempunctata,* against *Bemisia tabaci* and *Aleurodicus disperses* whiteflies was investigated by Atuncha *et al.,* in 2013. Their research revealed that *B. tabaci and A. disperses* nymphs are a food source for all four species. The feeding habits of the coccinellid *Clitostethus arcuatus* on the ash fly *Siphoninus phillyreae* were investigated by Tavajdoh *et al.,* in 2009. All the larval stages of *C. arcuatus* feed on all nymphal stages of ash fly showing more preference for eggs of the fly. The predatory potential of coccinellid beetles on insect pests is well documented. A few studies have been summarized in Table 1.

Coccinellids feeding on fungal pests (*Mycophagous coccinellids*)

Giorgi *et al.,*'s molecular phylogenetic investigation from 2009 showed that Halyziini originated inside the Coccinellini tribe, which is often aphidophagous. Leschen (2000) suggested a straight forward theory in which prehistoric mycophagous beetles initially specialized as eaters of sooty molds before accepting the insects that were indirectly responsible for the mold's production as food sources. The fact that numerous hemipteran predators, including many coccinellids, continue to consume honeydew and sooty mold supports this theory (Majerus, 1994; Lundgren, 2009a, b). Since the spores were discovered both with and without aphids, it is likely that these fungi serve as a significant seasonal food source for the aphid predator. Phytophagy in the Epilachninae and mycophagy (both facultative and obligative) in the Coccinellinae have developed from a shared coccidophagous ancestor, according to Giorgi *et al., Propylea quatrodecimpunctata (L.)* (Turian, 1971; Hukusima and Itoh, 1976) *and Rhyzobius litura (F.)* (Ricci, 1986) both have facultative mycophagy, and mixed feeding on pollen, mildews (Erysiphales), and aphids. Hodek & Honek (1996); Samways *et al.,* (1997) and Lundgren

(2009a) claim that there is a poorly understood subfamily of *Polyphagous coccinellids* within the Coccinellinae that frequently consumes fungus along with pollen, arthropods, and perhaps certain plants.

Mycophagy among coccinellids may be facultative or obligatory. Facultative mycophagy may be frequent in the mostly aphidophagous Coccinellini tribe (Majerus, 1994). These predators regularly consume a variety of foods, including fruit, leaves, fungus, pollen, nectar, and honeydew, but specialized animal meals (e.g., aphids) are required for full development (Hodek, 1973; Lundgren, 2009b). It has been observed that *Rhyzobius litura* (F.) and *Propylea quatuordecimpunctata* (L.) both engage in mixed feeding on pollen mildews, or facultative mycophagy (Erysiphales) and aphids (Turian, 1971; Hukusima and Itoh, 1976). Members of the Halyziini tribe of the Coccinellinae are obligatory mycophages (Gordon, 1985), however, some studies have noted phytophagy (herbivory on higher plants) or aphidophagy (Schilder and Schilder, 1928; Borner and Heinze, 1957; Fulmek, 1957; Omkar and Pervez, 1999). According to Pakaluk *et al.,* (1994), the obligatory mycophage Halyzini feeds on the powdery mildew fungus that infects over 10,000 angiosperms worldwide. Until recently, no Halyziini member had been documented to feed on fungi other than Erysiphales (Sutherland and Parella, 2009). Culk *et al.,* 2011 studied the feeding of coccinellid *Psyllobora rufosignata* on the fungus *Phakopsora euvitis*. This is the first time any Halyziini has been observed feeding on a Basidiomycota species. *Mycophagous coccinellids* have the potential to be exploited as biological control agents for a variety of fungal infections. The beetle *Pyllobora vigintimaculata* is an obligate consumer of various fungi. In a laboratory setting, Illeis cincta Fab, biology was examined by Darshini *et al.,* in 2018 on sunflower leaves that had powdery mildew *Erysiphe cichoracearum* infection. Their studies showed that the highest spores were ingested by adult beetle followed by the third instar larva. The grubs of *Pyllobora bisoctonotata* feed perfectly on the powdery mildew (*E. polygoni*) of black gram plants. According to Maurice's research on the growth of the mycophagous ladybird beetle *Psyllobora bisoctonotata* on the powdery mildew *Erysiphe polygoni* of Black Gram (*Vigna mungo* L. HEPPER), the third instar larva is much more voracious than the others. Irfan *et al.,* (2011) studied the feeding potential of *Halyzia tschitscherini* against powdery mildew *Phyllactinia corylea* in mulberry and the results of their study indicated that the beetle *Halyzia tschitscherini* can be used as a potential biocontrol agent in seri- ecosystem. Satti, 2013 reported *Psyllobora bisoctonotata* (Muls.) as a potential feeder of powdery mildew on the wild plant *Xanthium brasilicum* in Sudan. This is the first record of a mycophagous insect in Sudan.

Methods to enhance pest control by coccinellids

To enhance the predatory capacity of coccinellids comprehensive studies are required to find out the ways to increase the efficiency of coccinellids as biocontrol agents. There are various factors that affect the predatory potential of coccinellids. Food quality is one of the most important factors determining the fitness of predatory coccinellids (Kalushkov & Hodek, 2005). Prey preference of coccinellids must be considered for efficient biological control of various pests because when coccinellids are given different foods they prefer the most suitable one for their better survival. Keshavarz *et al.,* (2015) studied the preference of two populations of ladybird beetle *Propylea quatuordecimpunctata* for two aphid species *Aphis fabae* and *Aphis gossypii* and they found that the beetles prefer *A. gossypii* over *A. fabae*. The temperature of the area also plays an important role in the efficiency of consumption of pests by coccinellid beetles. Schwarz *et al.,* (2019) studied the consumption of aphid by three common coccinellid beetles species and found the consumption of aphids by beetle’s increases with an increase in temperature. Nyukuri *et al.,* (2012) studied the effect of different ecological factors on the population of coccinellids and showed that temperature positively correlates with the abundance of coccinellids with Pearson coefficient of 0.159.

Table.1 Different Coccinellid species feeding on various Insect Pests

S. No	Coccinellid species (Predator)	Target organism (Prey)	References
1	*Coccinella septempunctata*	*Brevicoryne brassicae*	Rajan *et al.*, (2018)
2	*Coccinella septempunctata*	*Aphis gossypii*	Sattar *et al.*, (2008)
3	*Coccinella septempunctata*	*Lephaphis erysimi*	Kumar *et al.*, (2019)
4	*Hippodamia convergences*	*Lephaphis erysimi*	Pal and Bhatt (2018)
5	*Hippodamia convergences*	*Myzus persicaenicotianae*	Katsarou *et al.*, (2005)
6	*Harmonia dimidiate*	*Aphis pomi*	Kumari (2018)
7	*Ceratomegilla undecimnotata,* *Hippodamia variegate,* *Coccinella septempunctata*	*Myzus persicaenicotianae*	Skouras *et al.*, (2015)
8	*Chilocorus infernalis*	*Diaspidiotus perniciosus*	Khan (2010)
9	*Harmonia octomaculata*	*Acyrthosiphon pisum*	Sheela and Shinde (2019)
10	*Illeis indica*	*Peregrinus maidis*	Fisk *et al.*, (1981)
11	*Cleobora mellyi* *Harmonia conformis*	*Chrysophtharta bimaculata*	Baker *et al.*, (2003)
12	*Cryptolaemus montrouzieri*	*Phenacoccus solenopsis*	Kaurand Virk (2012)
13	*Delphastus pusillus*	*Bemisia tabaci*	Hoelmer *et al.*, (1993)
14	***Nephaspis oculatus*** ***Delphastus catalinae***	***Bemisia argentifolii***	Liuand Stanly (1999)

Fig.1 The various stages of life cycle of Coccinellids

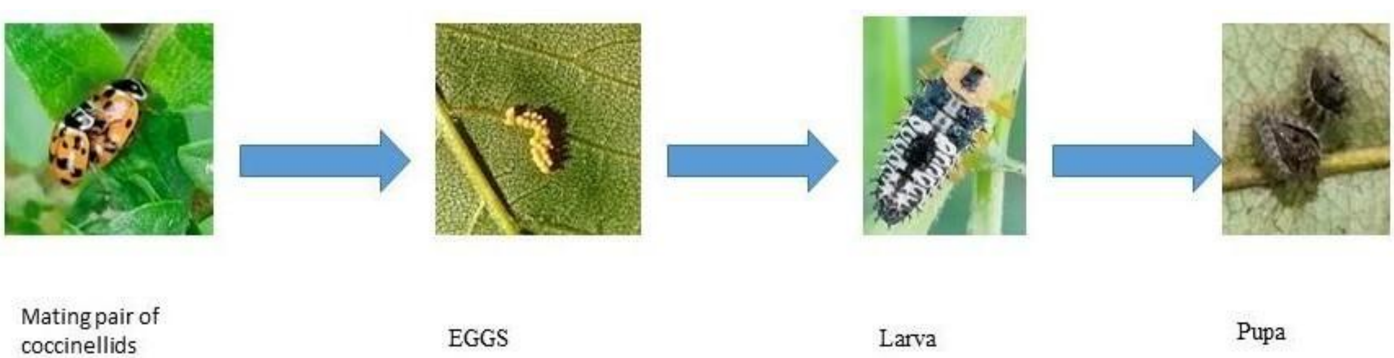

Fig.2 First instar of Vedalia Feeding on scale eggs. University of California, Division of Agriculture and Natural Resources. http://anrcatalog.ucdavis.edu/

Hunger also increases the consumption rate of prey by coccinellids. Suleman *et al.,* (2017) observed that starved beetles consume more aphids than unstarved aphids, also the preference of food also changes in starved and unstarved conditions.

Due to their repellent or antifeedant qualities, pesticides may impede the feeding behavior of exposed insects (Desneux *et al.,* 2007). Pesticides have an impact on the predatory efficacy of the beetle, according to a study by Afza *et al.,* in 2020 that examined the impact of six pesticides on the survival and predatory activity of *Coccinella septumpunctata*. Sutherland *et al.,* (2010) investigated the effect of fungicides on mycophagous coccinellid larval mortality and discovered that wettable sulphur and myclobutanil fungicides increase larval mortality in *Psyllobora vigintimaculata*.

Sugar spraying on crops increases the number of coccinellids. In 2010, Seagraves *et al.,* investigated how carbohydrates affected the density of coccinellids in US soybean crops. On soybean fields, sucrose was sprayed, and they discovered that total coccinellid densities were 50–77% higher in the sugar-sprayed areas than in the unsprayed areas.

Coccinellids have a lot of potential when it comes to controlling insect pests and fungus-sooty molds. To improve the growth of coccinellids for biological control, a complete approach is required, and a shift away from the traditional pesticide and fungicide approach is urgently required. For successful biological control, the prey population should be less disturbed and this can be achieved through minimal use of pesticides (insecticides and fungicides). Though effective in reducing prey population pesticides have a negative impact on the environment. In response to this biological control is environment friendly and possesses lesser impact on human health and domestic animals. Studies on the effects of chemical insecticides on predatory coccinellids have revealed significant differences in the toxicities of different pesticide classes and coccinellid species. Although augmentation releases of certain coccinellid species are well documented and beneficial, ineffective species are still employed due to ease of collection. In augmentation, mass production of natural enemies is done and released periodically so as to increase their effectiveness of control. They are released with the goal of permanent establishment. Most of the Homoptera and Acarina species are considered important pests, and these pests are preyed upon by a variety of predatory ladybird beetles. As illustrated by the research above, these predatory coccinellids contribute to a high level of regulation of their prey. These ladybird beetles may be combined with other predators or parasitoids to provide effective pest control, which would benefit the general public. As both their larvae and adults have predatory capacity in nature, they can be used as effective biocontrol agents for pests and fungus-caused sooty molds. Keeping in view their economic importance, more attention and research are needed to enhance the biocontrol potential of predatory coccinellids.

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