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Coccinellids as biological control agents of soft bodied insects: A review

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Abstract
Ladybird beetles (Coleoptera: Coccinellidae) are a species-rich, ecologically diverse group of substantial agricultural significance, inhabit in all types of terrestrial ecosystems. In the present review the biological control of soft bodied insects by ladybird beetles is analyzed. The family Coccinellidae comprises 6,000 described species worldwide, of which 90% are considered beneficial predators and is divided into six subfamilies: Sticholotidinae, Chilocorinae, Scymninae, Coccidulinae, Coccinellinae and Epilachninae although a recent phylogeny suggests a seventh subfamily, Ortaliinae. They have great economic importance as natural enemies**,** exhibit a predatory nature against many soft bodied insect pests such as aphids (Aphididae: Homoptera), scale insects and mealy bugs (coccoidea: Homoptera), whiteflies (Aleyrodidae: Homoptera), Thrips (Thripidae: Thysanoptera), jassids (Cicadellidae: Homoptera), psyllids (Psyllidae; Homoptera), small larvae, insect eggs, and phytophagous mites. These have been used in both classical and augmentative biological control programmes and are also considered important in conservation biological control programmes. They are of high priority in organic cropping and integrated pest management systems.

Keywords: Coccinellidae, Biological Control, Economic importance, Insect pests, Ladybird beetles, Natural enemies, Predators

1. Introduction
The family which the lady beetles belong, the coccinellidae, is extremely diverse in their habitat. They inhabit in all types of terrestrial ecosystems. They are one of the most important group of the natural predatory or enemy complex of many horticultural and agricultural crop pests [29, 93]. They belong to the order Coleoptera, suborder Polyphaga, super-family Cucujoidea and family Coccinellidae. The family Coccinellidae comprises 6,000 described species worldwide and is divided into six subfamilies: Sticholotidinae, Chilocorinae, Scymninae, Coccidulinae, Coccinellinae and Epilachninae although a recent phylogeny suggests a seventh subfamily, Ortaliinae [120]. Of these, only one subfamily (Epilachininae) is phytophagous; the rest are predacious in nature. Most authors divide the family into two major groups based on feeding preference: phytophagous or predaceous. A few lady beetles supplement their diet with pollen or nectar, and at least one group (Halyziini) is primarily mycophagous). Coccinellids are among the best-known beneficial predatory insects. The predaceous beetles exhibit a predatory nature against many soft bodied insect pests such as aphids (Aphididae: Homoptera), mealybugs (Pseudococcidae: Homoptera), whiteflies (Aleyrodidae: Homoptera), Thrips (Thripidae: Thysanoptera), jassids (Cicadellidae: Homoptera), and psyllids (Psyllidae; Homoptera) [124]. They also prey on small larvae, insect eggs, and phytophagous mites, which are injurious to agricultural and forest plantations [38]. Ladybirds are generally considered useful insects and one of the greatest allies of the farmers and the gardeners as many species feed on aphids or scale insects, which are pests in gardens, agricultural fields, orchards and similar other places. They are nature’s own pest controllers and more effective than poisonous chemicals [109, 111].

Hawkeswood reported about 5200 species of coccinellid worldwide [44]. Vandenberg provided a list of 6000 species in 370 genera of Coccinellidae worldwide, while Ślipiński reported 6000 species in 490 genera [125, 120]. The Coccinellid species known from Canada and the United States have been described, keyed and illustrated in a comprehensive review by Gordon [38].

The list for ladybirds in eastern Russia was published by Kuznetsov and in this list 92 species of ladybird were identified [74]. Canepari studied the Ladybird species in the Himalayas and Nepal and new species were recorded for the region [19].

The list of coccinellidae species in Khorramabad district of Lorestan province of Iran has been reported by Ansari [5]. In this research 22 species of coccinellids were recorded from Iranian fauna. A list of ladybird species, in the Poona and Kashmir regions of Pakistan was compiled by Inayatullah *et al*., [54]. Initial documentation of predatory coccinellids of Pakistan was done by Irshad [56]. Afroze identified a family of predatory ladybirds in India [1]. Poorani, reported 400 species under 79 genera of coccinellid beetles from Indian sub-continent [98]. Recently, Shah and Khan published 17 species of predaceous coccinellids from agro ecosystems of Kashmir, belongs to 15 genera and three subfamilies viz. Coccinellinae, Chilocorinae and Platynaspinae [113].

The majority of coccinellid species are beneficial predators (others are phytophagous or mycophagous); consequently coccinellids have played a significant role in the development of biological control strategies [11]. Predation by adults and larvae of the coccinellid beetles can have a major impact on populations of immature stages of these insects [104, 67]. Despite their prey of choice, most predatory coccinellids include other non-prey items in their diet (e.g. honeydew, pollen, sap, nectar and various fungi [79].

2. Brief biology and Ecology of Ladybird beetles

The life history of ladybirds revealed from eggs to adult, female is larger than males. Ladybirds produce larvae which undergo 4 instars before pupation and form adults. The color of larval stages varies among the species [29]. Freshly hatched larvae are grayish or black with yellow, orange and red color spots on dorsal side of body. Larvae grow from less than 1 mm to about 1 cm in length and large larvae may travel up to 12 m in search of prey, they fully grow in 2-3 weeks. Last larval instars pupate while attaching to a leaf, stem or other surfaces and emerge as another adult ladybug [110]. The pupae of aphid-feeding ladybird beetles are of pale color with black spots on dorsal side of body. Cannibalism of eggs, larvae and pupae are common, especially when prey is scarce. Beetles of certain species are entirely yellowish white after emergence. Marking occurs gradually and beetles become red or dark. Adult body shape varies from round, elongate, circular to oval shape. Head usually concealed under thoracic pronotum, mouth parts are of chewing-biting type and with club-shaped antennae [104]. Body with or without pubescence; eyes large, coarsely or finely faceted, occasionally *(Chilocorus*, etc.) partially divided by laterally expanded genae; antennae inserted close to inner margins of eyes, of moderate length or short, terminating in a three-segmented club ; mandibles with two (six in *Subcoccinella)* internal teeth on each ; maxillary palpi four-segmented, apical segment of maxillary palpus never aciculate, galea and lacinia separated, mandible with reduced mola; five pairs of abdominal spiracles, tentorial bridge is absent, anterior tentorial branches are separated; front clypeal suture absent, front coxal cavities open posteriorly, middle coxal cavities open outwardly; metaepimeron parallel-sided, femoral lines present on abdominal sternite 2; tarsal formula 4-4-4 or 3-3-3, tarsal segment 2 usually strongly dilated below. The colour of the larvae varies, but often they are bluish-grey with light-coloured spots. The head has three ocelli on either side. The legs are long and slender. Pupation takes place on the spot where the larva has been feeding, the hind end of the larva being anchored to the plant tissue by a secretion [73]. Generally ladybird beetles are multi-voltine (have many generations per year) and hibernation (activity ceased) occur during winter months. Adult lived for few hours to over a year. Their bright color and pattern not only make them attractive visitors to the garden, but also help to protect them by warning potential to predators of their distastefulness. They exude an unpleasant yellow substance (reflex blood) from their leg joints when attacked which is rich in toxic alkaloids. Their coloring is likely a reminder to any animals that have tried to eat their kind before. A threatened ladybird may play both dead and secrete the unappetizing substance to protect itself [109, 111].

Adult ladybugs eat aphids, while larval ladybugs also eat aphids, thus, it is uncommon in the world of complete metamorphosis (egg to larva to pupa to adult) for the larvae and adults to eat the same food in agricultural crops [16,110]. A single adult may consume more than five thousand aphids in its whole life span. Aphid feeding ladybird beetles are more active than scale insects feeding ladybird beetles their development, age and movement will be faster, and are also typically larger and lays their eggs in clusters. While as scale feeding coccinellids develope more slowly, lives longer, moves more slowly, and is typically smaller and lays their eggs singly [29].

Ladybirds lay hundreds of eggs in the colonies of aphids and other plant-eating pests. When they hatch, the ladybird larvae immediately begin to feed. By the end of its three to six week life, the alligator-like larvae (aphid wolf) may eat some 5,000 aphids suggested that one larva will eat about 400 medium-size aphids during its development to pupal stage and an adult lady beetle may eat over 5,000 aphids during its lifetime (about a year). Reddish-orange lady beetles eat aphids, and darker ones more often eat spider mites, whiteflies and scale insects. The best time to release lady beetles into garden is late in afternoon or at sundown, which can encourage them to stay for night and find suitable food and protection. Ladybugs in temperate areas usually hibernate through the winter as adults often in large groups. Millions of them may come together in few parts, where they cover the ground like a brilliant blanket. Crops which support aphid populations include wheat, sorghum, sweet corn, alfalfa, soybeans, peas, beans, cotton, potatoes, brassicacious crops, tomatoes, asparagus and apples. Besides aphids, they include in their diet adelgids, mites, insect eggs and small larvae. They also eat pollen which may constitute up to 50% of their food intake, nectar, water and honeydew. When normal prey is scarce, both adults and larvae sometimes exhibit cannibalistic tendencies, eating eggs, larvae and pupae of their own species. Lady beetles can be found in many habitats, including back yard landscapes, vegetable gardens and commercial farms, fruit orchards and vineyards, and natural areas anywhere their food sources are abundant. If aphids are scarce, lady beetle adults and larvae may feed on the eggs of moths, beetles, mites, thrips and other small insects, as well as pollen and nectar, or they may also be cannibalistic. Because of their ability to survive on other prey when aphids are in short supply, lady beetles are particularly valuable natural enemies. The length of the life cycle of *Coccinellids* varies depends on temperature, rainfall relative humidity and food supply. Usually the life cycle from egg to adult requires about 3-4 weeks or up to 6 weeks during cooler months. In cooler months, over wintering adults find food then lay 50-300 eggs in their lifetime among aphid colonies. Eggs hatch in 3-5 days and the larvae feed on *Aphids* or other insects for 2-3 weeks and then pupate. Adults emerge in 7-10 days. There may be five generations per year. In extremely low temperatures such as in autumn, adults hibernate, sometimes in large number, in plant refuse and crevices, beetles are always found under leaves which protect them from cold winter temperatures. The larvae are the most active during the day. They tend to be positively phototaxis and negatively geotaxis, meaning that they move towards light and away from gravity, which will lead them to the top of the plants where the *Aphids* live [110].

3. Effectiveness of ladybird beetles

Lady beetles are voracious feeders and may be numerous where preys are plentiful and broad spectrum insecticide use is limited. Lady beetles are effective predators if aphids are abundant (high pest density), but are thought to be less effective at low pest densities. Lady bird beetles differ in prey consumption rates on various prey species, it is attributed to various factors such as prey mobility [29], nutritional status [122], suitability of the prey for the growth and reproduction of the predator [48], prey size [57], effect of host plant of prey [126], etc. As *A. craccivora* was reared on a legume host, it is expected to possess a higher percentage of protein nitrogen which could possibly make it a comparatively more preferred prey [7]. Other factors such as intrinsic growth rates, host patchiness, predation and competition, host traits, etc. also have a major influence on the efficiency of predator in managing prey population. Resource concentration through increased botanical diversity may be yet another factor that could affect the diversity and relative abundance of various ladybeetles in various ecosystems under consideration. It was studied that the effects of intercropping systems on diversity and composition of predatory arthropods in vegetable fields and reported higher species richness and diversity indices in intercropping systems than in monocultures [51]. Intercropping with aromatic plants significantly improved the diversity and various diversity indices of natural enemies [119]. The cultural operations such as extent of weeding and pruning could also affect the diversity and abundance of natural enemy assemblages. There was higher abundance of coccinellid species in partially weeded plots of rice and cowpea than weeded plots [105].

The Pesticide treated ecosystems in Kashmir were found to support less number of ladybeetles. The sprayed orchards were found to have 14 species of as compared to 17 in unsprayed ones. Similarly, only 10 species were recovered from the sprayed vegetable fields as compared to 12 from unsprayed fields. The biodiversity indices indicated appreciable effect of pesticide application on the coccinellids assemblages [113]. There are two ways in which pesticide treatments probably influenced the coccinellid assemblages are; the direct toxic effect of pesticide applications and the indirect effect through changes in prey abundance and distribution [78].

Biological control agents are important parts of integrated pest management (IPM) in the greenhouse. For them to be effective, growers have to monitor their crops frequently for the first sign of insect pests. Once found, a pest must be quickly and accurately identified so that an appropriate biocontrol species can be purchased while the pest population is still low. If the pest population becomes high, then biocontrol rarely provides satisfactory control because they cannot reproduce as fast as the more numerous pests unless one is willing to pour a lot of money into the task. Before and after introducing a biocontrol, pesticides must be avoided or carefully selected so that good bugs are not killed along with pests [35, 91]. These predators are collected in the wild and their availability is good, except during the early summer months when their supplies may be sold out. Ladybugs can be stored in the refrigerator for several weeks and released one handful at a time. They are usually thirsty when released, so plants should be misted prior to release. Accordingly, releasing them in the evening is also important [17]. The best time to release lady beetles into the garden is late in the afternoon or at sundown; this will encourage them to stay for the night and find suitable food and protection. Dampen of the ground or plants before releasing of lady beetles, will encourage them to stay and drink water. Release lady beetles at the base of plants; as their instinct is to climb the nearest plant and hunt for food. Release groups of lady beetles at 20 feet apart or more so that they can hunt for food. About 1,000 lady beetles can rid an acre of ground of most soft-bodied pests [33]. Early evening is the best time to release ladybugs and it gives them all night to settle in, find food and water, and realize they have found a good home (garden). Ladybugs are usually thirsty from their long journey and storage, and appreciate moist places to drink. If necessary, sprinkle some water around first before their release. Later on, they may get most of their moisture needs from eating aphids and other juicy plant pests. Proper identification of predators and distinguishing of pests from natural enemies is essential for effective biological control. Carefully, observe the mites and insects on plants to help discern their activities [26].

4. Coccinellids in biological control

The term biological control was defined by DeBach (1964) as the action of parasites, predators or pathogens in maintaining another organism's population density at a lower average than would occur in their absence. In the ecological sense, it refers to the ' top - down ' action of predators, parasites or pathogens on organisms occupying a lower trophic Level, action that maintains their populations at lower levels than would occur in the absence of these natural enemies, i.e. a natural process that does not depend on any human intervention. In the applied sense, it refers to the specific use or manipulation of population of natural enemies to reduce the pest population to tolerable level. Biological control is economically viable, of low environmental impact, and does not present risks of environmental contamination. It does not present risks for human health nor for domestic animals. From the economic standpoint, an effective natural enemy is the one capable of regulating the population density of a pest, maintaining it below the economic damage level established for a given crop. In general, the most effective natural enemies should present the following characteristics: adaptability to environmental physical conditions changes; a certain specificity degree to a given host/prey; high capacity of population increase in relation to its host/prey; high searching capacity, especially at low densities of host/prey; seasonal synchronization with its host/prey and the ability to survive in the absence of the host/prey; ability to change its action as function of its own density and that of the host/prey, i.e., to demonstrate reciprocal density; it should have quick power for dispersal in a locality and it should not become a pest of any economic plant or animal [28].

Owing to the seasonal synchrony with specific preys, high foraging performance and high reproductive efficiency, the coccinellids have the potential to be effectively employed in integrated pest management programmes [75]. In addition to many attempts on their use in classical biological control, some being highly successful, ladybeetles are also being translocated or mass produced and released for the control of various pests [117]. Lately, the role of generalist predators such as ladybeetles is being recognized in conservation biological control through conservation and enhancement techniques [92]. About 90 % of coccinellids are beneficial predators. By definition, predators are free living organisms, usually greater than their prey, and require several individuals to complete their life cycle, which are externally attacked and devoured. However, when predator insects and mites are mentioned, some changes must be made on the definition: the size of the predator in relation to prey is variable, since, though not usual for arthropods to attack in schools to dominate larger prey than each individual, it is extremely common for them to have some tools to facilitate predation. Therefore, insects which are relatively smaller than their prey can dominate them, depending on the modifications that they present. Several insects and mites are predators during their whole life cycle. However, some insects do so only during the juvenile stage or during their adulthood. Predators are basically chewers or suckers, but there can be combinations of these habits. In general, predators can be considered generalists in relation to their prey. Three major categories of feeding habits generally are recognized for coccinellids: predation (zoophagy), plant feeding (phytophagy), and fungus feeding (mycophagy).

Biological control involves three major techniques, viz. importation (classical biological control or introduction), conservation and augmentation. Classical biological control refers to the intentional introduction of an exotic biological control agent for permanent establishment and long-term pest control [32]. Augmentation refers to the mass production and periodic release of natural enemies of the pest, in order to increase their effectiveness of control, but without the goal of permanent establishment. It involves two techniques inundative and inoculative biological control. Inundative biological refers to the use of living organisms to control pests when control is achieved by exclusively by the organisms themselves that have been released whereas, inoculative biological refers to the the intentional release of a living organisms as a biological control agent with the expectation that it will multiply and control the pest for an extended period, but not that it will do so permanently [32]. All the three major techniques have their applications in coccinellids. The predaceous coccinellids are linked to biological control more often than any other taxa of predatory organisms. The beneficial status of these organisms has a rich history that is recognized by the general public and biological control practitioners alike [39, 47, 46]. Coccinellids play an important role in naturally occurring and human assisted biological control, and they are considered as possible natural enemies for importation whenever a homopteran pest invades a new region. Augmentative releases of several coccinellid species are well documented and effective; however, ineffective species continue to be used because of ease of collection. The role of naturally occurring Coccinellidae in suppressing pest populations is significant but poorly documented in many pest management programs [88].

Cryptolaemus montrouzieri Mulsant (Coleoptera: Coccinellidae) is arguably one of the most widely used biological control agents. It has many of the attributes as an effective natural enemy, including a rapid development rate, high reproductive potential, good adaptation to a range of tropical and subtropical climates, high prey consumption rates by both adults and larvae and ease of rearing. The first introduction of this ladybird for biological control dates back to 1891 when Albert Koebele brought it into California for control of Planococcus citri Risso [10]. Since then, the beetle has been introduced into many countries around the world. Most recently, it was introduced in parts of the Caribbean and Central and South America for control of the hibiscus mealybug, Maconellicoccus hirsutus Green [60, 83]. The coccinellid has been introduced into at least 64 countries/territories to control more than 16 pest species. It is a polyphagous predator that exploits hosts in at least eight hemipteran families. It is noteworthy that it has adapted to feed on new insect families in some new localities where it has been introduced. Although the wide host range has allowed its use against a variety of pest species, it is also a good indicator of the potential to feed on non-target species. In some countries, it is also used extensively for augmentative releases, for instance in citrus orchards in the Mediterranean, the former USSR and USA. In India, it is used in coffee plantations, fruit orchards and vineyards [127]. In South Africa, it is used against mealybugs in citrus. In India, maximum control of M. hirsutus on grape was attained 6–8 weeks after initial release of 1000–1500 (10 per vine) ladybirds per hectare [81]. In the Black Sea area of the former USSR, 5000 ladybirds per hectare were used with good results in tea plantations to control Chloropulvinaria floccifera Westwood [85]. Chloropulvinaria aurantii Cockerell was controlled in citrus plantations in Azerbaijan when 5000 C. montrouzieri were released in 3 ha of orchards [100]. Similar results were obtained for P. citri on citrus in Italy [77]. Repeated releases of the predator controlled mealybug pests on ornamental plants in European glasshouses [94]. In New Delhi, 2–3 larvae and adults of C. montrouzieri per tobacco plant controlled the mealybug, Ferrisia virgata (Cockerell) successfully within 1 month under glasshouse conditions [37]. One of the reasons C. montrouzieri has been so widely used is the fact that it is easy to rear. Indeed, rearing systems range from very simple systems producing a few thousand, to large systems producing several million beetles a year [108]. Mealybug hosts, primarily P. citri or M. hirsutus, are reared on bleached (etiolated) potato sprouts or pumpkin fruits. P. citri is thought to be better suited as a host because it has a shorter developmental period and higher fecundity. Numerous methods exist for rearing coccinellids on prey as reported by several authors like [42, 30]. Cannibalism by larvae or adults and artificial diets that support normal rates of coccinellid egg production are not commercially available, are persistent problems in mass rearing of many coccinellid species [103, 2]. Nutritional requirements for coccinellids, similar to other predatory groups, are very specific [23]. Generally, egg production on artificial diets has been observed for species with pinkish or pale colored adults. *C. montrouzieri* has been reared on a meridic (partially defined) diet [22]. and *R. cardinalis* has been reared and produces eggs on a holidic (chemically defined) diet. Females of aphidophagous species with orange-red adults (e.g. *Coccinella, Hippodamia*) do not produce eggs on artificial diets without supplemental feeding on aphids [42]. For most agricultural systems, conservation techniques for coccinellids are lacking, even though they are abundant in these habitats. The provision of overwintering habitats and refuges from pesticides in and near cropland are the core practices for the use of coccinellids in conservation biological control. In diversified ecosystems the diversity of natural enemies is also quite high. Factors that contribute to high level of natural enemies in these ecosystem are the availability of diverse microhabitats, alternative hosts and shelter all of which encourage colonization and population build up of natural enemies besides, greater availability of food sources (prey, nectar, pollen); provision of refuge, the abundance of floral nectar and alternative prey (aphids), shelter, mating and oviposition sites harbored in the border crop compared with monoculture having lesser biodiversity. In some situations, this may include reducing the application of pesticides, since such pesticides may kill predators at the same time as killing the pests. Sometimes part of a crop area is left untreated so that natural enemies will survive and recolonise the treated areas. Other non-insecticidal methods of pest suppression are given precedence over use of insecticides towards conservation of natural enemies [86]. Coccinellids are attracted to some flowering plant species like, *Achillea millefolium, Coriandrum sativum, Cosmos bipinnatus, Lobularia maritima, Medicago sativa, Petunia grandiflora, Phacelia tanacetifolia, Sinapis alba, Tagetes patula* and *Tropaeolum majus*). This knowledge can be implemented in conservation biological control strategies as these flowering strips provide to these beneficial insects as non-prey foods (floral nectar, pollen, honeydew, etc) and shelter are critical to the success of conservation biological programs [14,79]. As habitat manipulation is an important component of insect pest management in organic cropping systems, these results emphasize the importance of rigorous selection of plant species. The availability of alternative prey considered to be an important factor for the conservation of predators in agro-ecosystems. It includes those practices which favor survival and multiplication of natural enemies such as selective use of insecticides which do not kill natural enemies, provision of refugia and alternate hosts for natural enemies. Besides, cultural activities may be implemented or modified to facilitate natural biological control, or simply to spare beneficial species from adverse human impacts, including application of pesticides. The diverse approaches to achieving this end are now collectively termed as conservation biological control [8, 9]. Most coccinellid species are predaceous on honeydew-producing insects from the hemipteran suborder Sternorrhyncha, although some prefer other arthropod prey. Despite their prey of choice, most predatory coccinellids include other non-prey items in their diet (e.g. honeydew, pollen, sap, nectar and various fungi [96]. The exact role of these items play in the natural history of these predators is not well understood. It has been recently argued that these so called “alternative” food sources might play a more important role than it was originally suggested. In the classical view, “alternative” food is utilized to provide sufficient energy to compensate for metabolic losses or to accumulate reserves for dormancy whenever the preferred prey, or “essential” food, is scarce [47]. Coccinellid predators exhibit functional response, it is a key factor regulating the population dynamics of predator-prey systems. It describes 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 populations [66]. Or it is the change in the number of prey consumed per predator in response to changing prey density [49, 50]. The functional responses are usually measured to check the suitability of a predator as a biocontrol agent [65, 70]. The functional response may be constant (Type I), decreasing (Type II), increasing (Type III). This could further be simplified in terms of density dependence as constant (I), decreasing (II) and increasing (III) rates of prey consumption and yield density dependent prey consumption, respectively [95]. Coccinellids generally exhibit Type II functional response as reported for *Coccinella septempunctata*, *C. transversalis* and *Cycloneda sanguine* [95, 57]. khan (2009) showed clearly that the proportional consumption rate increased initially and declined later against the various densities of *B. brassicae* offered to *A. tetraspilota*, which is characteristic of Type II functional response as reported for *Adalia punctate* [65, 106], *Harmonia axyridis* and *Cheilomenes sexmaculata*, *A. tetraspilota*, *Coccinella septempunctata, Calvia punctata* and *Hippodamia variegate* [95, 66]. Functional response of a predator feeding on a particular prey species are described by two widely used parameters, these are the predator’s “attack rate” or search rate (*a*) and its “handling time” (*Th*) [43]. When the predator passes through a series of instars, different values of *a* and *Th* will characterize for each predator stage–prey combination.

The estimates of maximum number of aphids attacked per day as 33.5 for 4th instar larvae and 32.8 for adult females of H. variegata when A. craccivora was used as prey. The practical implication of these studies is that 4th instar larvae and females are the stages that are most effective as predators. It may be suggested that mass release of the predators in question may be most effective if releases are done primarily as last stage individuals (4th instars and adult females). Such releases would facilitate rapid killing of prey immediately after release. The sex ratio of mass produced ladybeetles if made to favour female individuals may be advantageous for biological control as adult females and 4th instar larvae are better in devouring of aphid prey. Rest of the predatory stages of both the predator species consumed lower numbers of prey individuals in the speculated period of time on any of the three aphid prey species used [114]. The maximum consumption by 4th instar larvae of *H. variegata* as 52.78 preying upon *A. fabae*. maximum consumption of 147.06 aphids per day for the adult females of *H. variegate* upon *Brcahycaudus helichrysi* [59, 58]. the search rate of *H. eucharis* showed that the fourth instar had higher search rate, whereas the handling time showed the opposite trend as search rate. Thus, suggested that fourth instar larva of *H. eucharis* is the efficient predator for the biological control of *A. pomi.* The first instar larva had a high search rate but not significantly higher than that of other stages while the handling time of the fourth instar larva was significantly lower than that of other stages. Actually, the maximum searching with shortest handling was determined by value of r2 at P<0.001 that was highest for the fourth instar larva (0.6383), followed by adult female (0.6264). The search rates (a) and handling time (Th) are presented in Table 1. The consumption of *A. pomi* by the larvae of *H.* axyridis increased significantly with age and the last instar larvae consumed maximum number of *A. pomi* under the various increasing densities. Similarly, the adult female of *H. eucharis* consumed more aphids than adult male, but less than the third and fourth instar larvae [69]. similar consumption of *Cinara* spp. by fourth instar larvae of *Cycloneda sanguinea* (L.) and *Hippodamia convergens* were reported [20]. The consumption rates of different instar larvae were varied due to their size and voracity. Large size coccinellids consumed more aphids than smaller ones. The female of two-spotted lady beetle, *Adalia bipunctata* ate more of pea aphid *Acyrthosiphon pisum* than males to meet growth and reproductive requirements [66, 106]. The univariate analysis of bio-efficacy of different species of *Coccinellids* preying on *Aphids* showed that all the species had a significant predation level (P < 0.05) with the larvae of *H. variegata* being the most bio-efficient consuming on average, 32.4 *Aphids* over the experimental period. On the other hand, adults of *H. variegata* were rated the least bio-efficient among all consuming on average, 12.11 *Aphids* during the same period. The consumption of *Aphids* by coccinellid adults was, in descending order as follows: *Cheilomenes* spp. (23.1 *Aphids*), *Henosepichna* spp. (17.33 *Aphids*) and *Exochomus* spp. (15.6 *Aphids*) Table 2. *Coccinellids* exhibited a positive functional response with a population density of 50 recording the highest number of *Aphids* preyed upon by the *Coccinellids*. The functional response was the lowest at lower aphid population densities. The effect of population density to functional response of *Coccinellids* was significant ($P < 0.05$). Their differences in functional responses were based on variation in size, voracity satiation time, and handling time (time spent by predators in attacking, killing, subduing and digesting the prey) as shown in Table 2 and 3 [89].

Apart from the predatory habit of coccinellids are the leaf-eaters, which are grouped within Epilachninae and the fungus feeders, which comprise two small groups from within Coccinellinae, Halyziini and some Tytthaspidini. The hemipteran suborder Sternorrhyncha is divided into four major divisions: Aphidoidea, Psylloidea, Aleyrodoidea, and Coccoidea [41].

4.1 Coccinellids as predators of Aphids

Aphidophagous species have a long history of importation in classical biological control programmes, albeit with few recognized successes. As early as 1874, *C. undecimpunctata***,** a relatively polyphagous species, was imported to New Zealand where it established to become an important predator of aphids and mealybugs in various fruit and forage crops [31]. The high reproductive rate of aphids is achieved through a combination of thelytoky and a telescoping of generations (live birth of pregnant daughters). Consequently, multiple aphid generations can be completed within the time required for a single generation of any coccinellid, forcing the numerical response of the predator to lag behind population growth of the prey. Borges *et al*. (2006) advanced the notion that the life history of ladybirds has evolved within constraints dictated by the ecology and distribution of their prey. They suggest that scale – feeding species have evolved a slow pace of life (slow development, low voracity and fecundity) in order to effectively exploit slowly developing prey that are continuously available, but widely distributed in small colonies. In contrast to scales, aphid colonies develop quickly and become much larger, but can be harder to find and more ephemeral in availability, attributes that favour their exploitation by voracious species that have faster development and higher fecundity. These disparities in life history, whether derived from predator – prey relations or not, suggest that aphidophagous coccinellids cannot be manipulated in biological control programmes by the same means, or for the same ends, as coccidophagous species, even though they may emerge as key sources of natural aphid mortality in field studies [25]. All three families of Aphidoidea are essential foods for some predaceous coccinellids. Aphids are the preferred prey of most Coccinellini, Platynaspidini, and most Aspidimerini. *Hippodamia convergens* and *H. axyridis* have both been released extensively throughout Europe for the control of aphids. *Hippodamia convergens* is native to America and several billion are collected annually from overwintering sites in California and sold throughout America. This practice has been shown to be highly ineffective because of adult dispersal [29]. *Harmonia axyridis* has been released as a classical biological control agent in North America since 1916. It has been commercially available in Europe since the 1980s and has many attributes that contribute to its economic viability, including its polyphagous nature. *Harmonia axyridis* preys on a wide variety of tree-dwelling homopteran insects, such as aphids, psyllids, coccids, adelgids and other insects [71]. *Harmonia dimidiata* was found in abundance in apple and blue pine plants in Kashmir. This species has been reported from north and north-eastern regions of India [115]. May-June is the peak period of its occurrence in the temperate region and August-September in tropical and subtropical regions. It was found feeding on Aphis pomi and Tetranychus urticae *in Kashmir.* Adalia tetraspilota (Hope) and Hippodamia (Adonia) variegata (Goeze) are the predominant species of coccinellids in agro-ecosystems of Kashmir valley. H. variegata originated in the Palearctic region and is a widespread predator of aphids in many parts of the world [57, 36]. This species is considered the most important natural enemy of aphids in many countries including Bulgaria, Ukraine, Italy, India and Turkmenistan [72]. About 17 species of predaceous coccinellids from agroecosystems of kashmir, belongs to 15 genera and three subfamilies viz. Coccinellinae, Chilocorinae and Platynaspinae have been reported. *Adalia tetraspilota,* is the most abundant in Kashmir and is recorded on all crops / plants surveyed except blue pine. In Kashmir, it is found to feed on *A. pomi, M. persicae, L. erysimi, B. brassicae, A. fabae, A. craccivora,* etc. In Kashmir region, the peak period is May-June [113]. This species has also been reported from Murree (Pakistan) feeding on Adelges spp.; *Q. perniciosus* and *D. abietiella* and from Nepal [56, 19]. *Hippodamia variegate, and Chilocorus infernalis feed on, A. pomi, Tetranychus urticae, M. persicae, L. erysimi, B. brassicae, A. fabae, A. craccivora, Q. perniciosus,* etc**.** in agroecosystems of kashimir India. *Harmonia eucharis* is found on fruit trees, *Euonymus* hedges and forest trees of Kashmir. Just before the start of autumn, it is found on blue pine trees in abundance and migrates to fruit trees in May [63]. This beetle is reported feeding in large numbers on different species of aphids in western, north-west Himalayas and northeastern regions of India in October and November [118]. *Coccinella septempunctata* is one of the most common and widely studied ladybird beetles, reported from India as well as different parts of the world [61, 3]. It is found on all fruit trees and cruciferous crops in Kashmir it feeds upon *Aphis pomi, Lipaphis erysimi, Myzus persicae, Brevicoryne brassicae* and other aphids. It can be seen throughout the year, but it is more abundant and active in May-July in Kashmir. Both the larvae and adults are voracious feeders of aphids and are effective in reducing their heavy infestations. This coccinellid was found to be predacious on almost every species of aphid. Besides, *Callicaria superba, Calvia punctata, Aiolocaria hexaspilota, Coccinella transversalis, Calvia punctata,, Oenopia conglobata, Propylea luteopustulata, Illeis indica, Oenopia conglobata, Menochilus sexmaculat, Chilocorus rubidus, Priscibrumus uropygialis, Platynaspis saundersi* are found in agro-ecosystems of Kashmir, India [69, 70].

4.2 Coccinellids as predators of whiteflies

The family Aleyrodidae comprises the commonly referred to whiteflies. Over fifty species of coccinellidae attack eggs and immature stages of whitefly pests. There is interesting variation in the predatory behaviour of these polyphagous coccinellids; some are mobile, seeking out prey, and others are sedentary, and complete pre-imaginal development on one leaf [90]. Aleyrodidae are the preferred food choice for the Serangiini (Sticholotidinae). Two important sticholotidine predators of Bemisia whiteflies are *Serangium parcesetosum* and *Delphastus catalinae* (Horn) [4, 116]. Within Scymninae, the genera Zilus Mulsant (Scymnillini) and Nephaspis Casey (Scymnini) also feed primarily on whiteflies. Nephaspis oculatus (Blatchley) is another important predator of Bemisia whiteflies [76]

4.3 Coccinellids as predators of scale insects

The vast majority of the Scymninae, Chilocorinae, Sticholotidinae and Coccidulinae prey on Coccoidea, Coccoidea including three economically important families (Diaspididae, Pseudococcidae and Coccidae). A number of coccinellid species have been used in historically significant and successful projects for the biological control of scales [15]. including *R. cardinalis* and *R. lophanthae*. *Rhyzobius forestieri*, *Nephus reunioni*, *Chilocorus nigritus* and *Chilocorus kuwanae* [15, 30]. *Rodolia cardinalis* has been heralded as a success story for biological control This species has been introduced into 33 countries to control *I. purchase* and has yielded complete control in 26 countries Morocco, Tunisia, Turkey, Egypt, India, Japan and New Zealand); substantial control in four(North America, Argentina, Peru,Chile, Portugal, Uruguay, Venezuela, France, Italy, Spain, Greece, countries (Russia, Libya, the Bahamas, Ecuador) and partial control in two countries (Seychelles and Mauritius)[18]. *Chilocorus infernalis* Mulsant (Coleoptera: Coccinellidae) has been evaluated against San Jose scale in apple orchards at five locations in farmers' fields in Kashmir during 2008. The predator was released @ 20, 25, 30, 35 / plant three times at 10 days intervals starting from 1st week of June. The population of San Jose scale was recorded before release and a month after release from three apple trees at each location selected at random. All the four rates of release were effective for the control of the scale. Release of *C. infernalis* @ 35 / plant significantly reduced the infestation of the San Jose scale in all locations of Kashmir [69]. The success of the vedalia beetle, and the publicity surrounding its economic benefits, became a watershed event that catalyzed the introduction of many exotic coccinellids targeting other pests, although rarely with the same degree of success [18]. The high degree of specificity of *R. cardinalis* for *Icerya* species, in combination with a very short generation time, highly efficient detection of isolated host patches, and the ability of a larva to complete development on a single mature female scale are all thought to be key factors in the effectiveness of the vedalia beetle [99]. A similar rate of success was achieved through the acclimatization of *C. montrouzieri* to control *Pseudococcus* spp. [55]. Therefore, *R. cardinalis* and *C. montrouzieri* have contributed economic benefits through the ecosystem service they provide. Many authors have noted the high success rate of coccinellids as biological control agents of coccids as compared to aphids [80]. The success of coccinellids as biological control agents of coccids is higher than that of aphids but still relatively low at only 40 % of cases studied being designated as exerting complete or substantial control. The lack of success of aphidophagous coccinellids has been attributed to asynchrony between the reproductive and development rates of the predatory coccinellids and their aphid prey [29]. Furthermore, many aphidophagous coccinellids, in temperate climates, are univoltine whereas aphids are multivoltine. Coccidophagous coccinellids tend to stay in a localised area throughout their life cycle and, in contrast, aphidophagous coccinellids disperse widely. The high reproductive rate of aphids is achieved through a combination of thelytoky and a telescoping of generations (live birth of pregnant daughters). Consequently, multiple aphid generations can be completed within the time required for a single generation of any coccinellid, forcing the numerical response of the predator to lag behind population growth of the prey [55]. The life history of ladybirds has evolved within constraints dictated by the ecology and distribution of their prey. The scale – feeding species have evolved a slow pace of life (slow development, low voracity and fecundity) in order to effectively exploit slowly developing prey that are continuously available, but widely distributed in small colonies. In contrast to scales, aphid colonies develop quickly and become much larger, but can be harder to find and more ephemeral in availability, attributes that favour their exploitation by voracious species that have faster development and higher fecundity. These disparities in life history, whether derived from predator – prey relations or not, suggest that aphidophagous coccinellids cannot be manipulated in biological control programmes by the same means, or for the same ends, as coccidophagous species, even though they may emerge as key sources of natural aphid mortality in field studies [15, 25].

4.4 Coccinellidae as predators of mites

Among the predaceous Coccinellidae, there are relatively few departures from the widespread reliance on hemipteran prey. The greatest deviation occurs in Stethorini (Scymninae) which prey on spider mites and false spider mites (Acari: Tetranychidae and Tenuipalpidae) [12] the only non-insects regularly utilized as essential prey by lady beetles [40]. Tetranychid mite outbreaks became common in many agricultural systems only after World War II, when widespread use of broad-spectrum insecticides increased. Stethorini were initially appreciated only for their ability to suppress severe outbreaks of tetranychid populations. However, research on their prey searching behaviors reveals that Stethorini use visual and olfactory stimuli to locate small mite colonies in patchy distributions, and can be very effective in regulating their prey at low densities. Moreover, acariphagous coccinellids colonize mite outbreaks earlier, and consume more pest mites, than many other mite predators. Stethorini have provided economically successful regulation of pest mites in several cases. Reasons underlying these success stories include (a) the regulatory potential of the long-lived adults; (b) the ability of adults to rapidly immigrate into cropland; and (c) the ability of non-pest tetranychid mite populations, non-tetranychid mites, extrafloral nectaries, aphid honeydew, and pollen, to support populations of Stethorini before pest mite populations reach outbreak proportions in crops [40]. Stethorini are present throughout the world in many different climates ranging from tropical rainforests to temperate deciduous forests and plains to colder northern regions of Europe, Canada, and Russia. *Stethorus punctillum* has the largest distribution in the group, ranging over most of temperate North America, Europe, and Asia. The current geographic distribution of Stethorini is due to the intentional redistribution by biological control scientists.

The best documented and most successful biological control program incorporating Stethorini has been that of S. punctum in apple and peach orchards of the eastern USA. Pennsylvania initiated a system for the biological control of mites using S. punctum during the 1970s [6, 27]. The program reportedly reduced acaricide usage by 1000 metric tonnes of formulated product, realizing a cumulative grower savings of US$20 million over 25 years [13].

Some attractive characteristics of Stethorini for mite biological control are their prey consumption, longevity and high reproductive capacity.Each adult female may consume 30–60 mites per day. Total fecundity ranges from 123 eggs in *S. tridens* [34], 184 eggs in S. madecassus [21], 221 in S. punctum [121], 279 in *S. punctillum* [107], to a high of 501 eggs in S. japonicas [84]. Developmental times for most species are approximately 17 d at 25 _C from oviposition to adult eclosion [121]. The number of Stethorini generations per year varies from 2 to 3 in temperate regions for S. punctillum and S. punctumto more than 15 per year for tropical species such as S. siphonulus and S. pauperculus[24]. Adult longevity is not known for most species, but appears to be longer in temperate species which undergo diapause than in tropical species, and is temperature dependent. *S. punctillum* females in Canada could commonly survive and lay eggs over multiple seasons under field conditions, with an average longevity of over 400 days; males generally die sooner than females [101]. Adults of both sexes of *S. vagans* in Australia lived 126 days at 12 °C compared to only 27 days at 30 °C. All Stethorini in temperate climates overwinter as adults, with a reproductive diapause that is induced by short day lengths and cooler temperatures. *Stethorus punctum* entered reproductive diapauses at day lengths of 10 h or less and 21–22 °C [123, 82]. *Stethorus japonicus* was induced into reproductive diapauses with day lengths shorter than 13 h at 18 °C. Species with large geographical ranges that include both temperate and subtropical climates may hibernate in the colder area but not in the warmer [62]. For example, S. punctum diapauses in Pennsylvania and in Washington state, but is active year round in southern California [52, 82]. Tropical species seldom experience diapauses. Several studies have shown that *S. punctillum* and S. punctum overwinter within fruit orchards and the adjacent habitat. Several classical biological introductions of stethornus species have been documented, besides considerable efforts went into the development of mass production methods using natural diets of mites and factitious prey or artificial diets [53, 21].

The success of coccinellids as biological control agents of coccids is higher than that of aphids but still relatively low at only 40% of cases studied being designated as exerting complete or substantial control. The lack of success of aphidophagous coccinellids has been attributed to asynchrony between the reproductive and development rates of the predatory coccinellids and their aphid prey. Furthermore, many aphidophagous coccinellids, in temperate climates, are univoltine whereas aphids are multivoltine. Coccidophagous coccinellids tend to stay in a localised area throughout their life cycle and, in contrast, aphidophagous coccinellids disperse widely [29, 53]. *Rodolia cardinalis* has been heralded as a success story for biological control. This species has been introduced into 33 countries to control *I. purchase* and has yielded complete control in 26 countries (North America, Argentina, Peru, Chile, Portugal, Uruguay, Venezuela, France, Italy, Spain, Greece, Morocco, Tunisia, Turkey, Egypt, India, Japan and New Zealand); substantial control in four countries (Russia, Libya, the Bahamas, Ecuador) and partial control in two countries (Seychelles and Mauritius). A similar rate of success was achieved through the acclimatization of *C. montrouzieri* to control *Pseudococcus* spp. Therefore, *R. cardinalis* and *C. montrouzieri* have contributed economic benefits through the ecosystem service they provide. Indeed, the initial cost of the *R. cardinalis* introduction programme in California 1888 was $1 500 with a return in just over a year of millions of dollars [18, 80].

Table 1: Stage-specific functional response of predaceous ladybird beetle, *H. eucharis* to green apple aphid, *A. pomi.*

Stages of *H. eucharis*	Parameter	Estimate	SD	*t* value	r2 at p<0.001	Residual SD
I instar larva	a	2.74106	0.35705	8.363	0.552	0.6167
	Th	1.57132	0.06207	29.817		
II instar larva	a	2.65137	0.29539	8.976	0.6238	1.129
	Th	0.89932	0.03587	25.072		
III instar larva	a	3.09049	0.36310	8.512	0.6235	1.384
	Th	0.77363	0.03251	23.796		
IV instar larva	a	2.76241	0.37895	7.290	0.6481	1.785
	Th	0.68211	0.03625	18.820		
Adult male	a	2.64471	0.38066	6.948	0.6047	1.216
	Th	1.09703	0.05316	20.635		
Adult female	a	3.06928	0.38820	7.906	0.6198	1.430
	Th	0.80856	0.03615	22.370		

Table 2: Bio-efficacy of different species of *Coccinellids* on *A. fabae.*

Specie	Stage	N	Mean	Std. deviation	Sum	Variance
Cheilom	Adult	9	23.1111	10.0180	208.00	100.361
Exochom	Adult	9	15.5556	5.7033	14,000	32.528
H. varie	Adult	9	12.1111	5.8190	109.00	33.861
H. varie	Larva	9	32.4444	11.033	292.00	121.778
Heosep	Adult	9	17.3333	6.3443	156.00	40.250
Total		54	17.4630	11.3864	943.00	129.650

Key: Cheilom = *Cheilomenes* spp.;Exochom = *Exochomus* spp.;H. varie = *Hippodamia* spp.
Heosep = *Henosepichna* spp..

Table 3: Functional responses of *Coccinellids* to varying population densities of *Aphids*.

Aphids Number	N	Mean	Std. Deviation	Sum	Variance
30.00	18	9.444	5.9530	170.00	35.438
40.00	18	18.888	9.1837	340.00	84.340
50.00	18	24.055	12.9682	433.00	168.173
Total	54	17.4630	11.3864	943.00	129.650

5. Summary and Conclusion

Coccinellid beetles are effective natural enemies for biological control of aphids, coccids, adelgids, aleyrodids, small larvae, insect eggs and phytophagous mites, which are injurious to agricultural and forest plantations. These are environment-friendly and more effective without any harmful effects on non-target organisms. These can be used in classical, augmentative and conservation biological control programmes, and possesses a tremendous potential in these regards. A variety of coccinellids are mass reared to assist in the management of insects and mites. Recognition of the ladybird beetles that naturally occur in urban landscapes is necessary for taking advantage of biological control and maintaining their natural order. Although biological control may be successful on its own, and no other control measures are required, it is almost always desirable to integrate biological control with other measures, including at times the careful use of pesticides in integrated pest management. This approach should be investigated and implemented for the benefits of farmers. The future studies should be made for improving conservation techniques and enhancing the efficacy of naturally occurring species in open systems. This can be achieved by providing a wide range of sources that will be made available in diversified ecosystem, such as flowering plants, legumes (peas, beans, clover and alfalfa), beetle banks etc. Besides, focus should be made on the proper identification of a wide range of predators which cover all major species in the pest complex of the crops and agro ecosystems. This would seem to be an important in view of the immense benefits attributed to predators as bio-control agents.

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