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Integrated pest management tactics and predatory coccinellids: A review

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Abstract

Integrated pest management, defined as an approach in comprehensive meaning by the selection, integration and implementation of sustainable pest control tools to keep pest status to endurable levels while maintaining a quality environment and mankind health. Why we need IPM? Utilization of chemicals as one and only choice for eradication of pest problems has been enormously criticized due to many reasons. For instance, negative impact of these pesticides on non-target organisms including natural predators and parasitoids of different insect pests, their high toxicity to environment and human beings and the rapid development of pesticide resistance in insect pests and disease pathogens are the most peculiar scenarios. A careful implementation of an IPM strategy is the only solution for alleviating these negative impacts of pesticides on environment and predatory ladybird beetles (Coleoptera: Coccinellidae) hold the premise for an increased reliability of biological control of insect pests and a successful integration of integrated pest management.

Keywords: IPM, Coccinellid beetles, Predator-Prey Relation, Cultural Control, Chemical Control, Biological Control

Introduction

Integrated vs Conventional Pest Management

Intellectually, integrated pest management (IPM) deals to manage pests zealously by using their interaction with other living organisms and with the environment [1]. IPM is going to be in advanced manner because bio-intensive IPM is at zenith of its fame by reliability now but previously conventional pest management has been applied as integrated pesticide management as name shows addictively using pesticides as a one or even last substitute. The main purpose of bio-intensive IPM is to reduce dependence upon pesticides and its flexibility makes it favorable in all cropping system [2].

Advantages of an IPM program over conventional pest management

In early 1960s, integrated pest control and pest management were treated identically and both were based on incorporating a number of control methods to manage pest with insecticides as one of the tool rather than only tool [3]. The term "Integrated Pest Management" was firstly used by Smith and Van den Bosch [4] and in 1969, this term was acknowledged by US National Academy of Sciences. IPM emphasizes on control measures rather than insecticidal because of its harmful effects to environment and on human health, hence conservation of beneficial organisms is encouraged. The natural occurring predator populations play a vital role in decreasing insect pest populations and mostly coccinellids prey abominately under greenhouse and under field conditions [5]. After the introduction of IPM, DDT was banned in early 1970s, by defaulting to secure environment. Therefore, bacterial insecticides (*Bacillus thuringeinsis* and other bacterial formulations) were released for control of lepidopterous pests that time and after that transgenic pest resistant crops were released to boast up suppression of activity of pesticides.

By extensive and non-integrated use of pesticides made certain pests become resistant against a wide range of pesticides that usually result into increase in pest population due to suppression of their natural enemies as a result of blind use of non-specific toxic and broad-spectrum pesticides [6]. Pesticides are hardly restrained to the target; therefore, residues may be meddling in natural activities of environmental components and increase risk for environment to become more toxic. Bio-intensive IPM appreciated more over conventional pest management because it showed no phytotoxic effects on plants along with permanency and cheap cost [7].

IPM tactics

Cultural control

By meddling in activities of agro-ecosystem to make environment hard for survival of insect pests, different cultural practice tools such as pattern of crops, preparation of soil, removal of crop residues, and non-crop vegetation are manipulated to manage or control insect pest populations below economic threshold level. These practices ultimately enhance natural population of enemies of different insect pests.

Habitat Stability

Annual crops are less likely to be an effective habitat rather than perennial crops such as an orchard which favors natural enemies. Grass strips around fields have a significant influence on population dynamics of natural enemies. These natural vegetation belts, for example, tend to increase predatory beetles and as a result lowering the aphid populations [8-10]. Albeit, there are some examples of harvest modification to allow for conservation of beneficial fauna such as alfalfa strip harvesting [11] and relay cropping [12, 13].

Crop Rotation

Crop rotation maintains the land by the cultivation of one crop after another and destroys insect pests' habitat by providing non-host environment. Rotation justifies only when there should not a particular crop to be grown anywhere in surroundings. By breaking down the life cycle of insect pests due to habitat or host elimination by crop rotation, many agricultural crops can be saved to some extent from insect pest damage [14, 15].

Many soil insect pests such as wireworms, termites, scarabeid grubs, cutworms and shoot-boring flies and many crop midges such as pea midge and bladder pod midge can be eradicated from field by crop rotation [14]. In corn to soybean rotation, corn is a grass whereas soybean is a leguminous broadleaf. Both of these crops have different insect pest complex. Corn rootworm, is a vigorous pest of corn and eradicated by using this rotation [7, 16].

Intercropping

Intercropping refers to growing of more than one crop in a uniform field and, hence, lowering down the insect pests and enhancement of their biodiversity of their natural enemies [14]. One of the aims behind intercropping is to tackle a serious pest to less economic crop rather than highly one. For this purpose, maize is intercropped with cotton to allow lepidopteran pest *Heliothis* caterpillars, gets feed from maize. But always boll formation in cotton should be synchronized with tasselling in maize; otherwise cotton will get attacked by *Heliothis* [17, 18]. Due to more diversity of crops in intercropping pattern, more predators are attracted for nectar or honey to feed on insect pests ultimately and more vegetation crops lead to humid conditions which encourage predatory beetles as well. In winter wheat, predatory beetles preferred weedy field rather than clean plots [14].

Trap Cropping

Trap cropping is a manipulation of insect pests by trapping them towards their more favorable hosts which are planted in different patterns and are least economic for the growers. These trap crops should be in, across and might be alongside the main crop having more attractive qualities and, hence, restrict the pest population in specified areas [19, 20]. By increasing predatory activity of natural enemies in trap crops due to more insect pests, control measure should be targeted there to get rid of these herbivores [21] and activity of predators may not effected by insecticidal control on small trap crop. Early planted potatoes could be a good trap crop for Colorado potato beetle (*Leptinotarsa decemlineata*) emerging in spring [22].

Cover Cropping

Cover cropping pattern do influence on soil structure and texture, land erosion control, and most importantly, insect pest control [23, 24]. So, cover crops have an ability to interrupt the activities of insect pests and reduce their lavishness. It is clear that presence of predatory activities in soil encourage crops to flourish zealously and increase resistive pressure against insect pests but it is true for more crops and false for some [24]. For example, in some studies, clover cover crops in cotton have positive effect on increasing population of natural enemies [25], while no effect has been found by Ruberson *et al.* [26]. Cover crops provide microhabitat, favorable to insect natural enemies and increase their numbers [27, 28].

Manipulation of Non-Crop Vegetation

Non-crop vegetation might be within or across the main crop, effective for natural occurring enemies in such a way that vegetational diversity let them to conserve. For example plantation of water chestnut (*Eleocharis* spp.) with in rice paddies, influenced on parasitoid *Tetrastichus schoenobii Ferriere.*

Resistant varieties

Host plant resistance technique is one of the best among all other control tactics of an IPM program. Resistive quality of host plant and manipulation of natural enemies play a vital role in pest management program [4, 5, 29, 30]. If one completely relies on plant resistance tool for insect pest management, then, one should lose some of other desirable crop produce such as yield [5, 31]. Most of insect pests are controlled by resistive quality of host plants but not all the insects. Karishna, Mahalaxmi, Khandwa 2 and MCU 5 are cotton cultivars and resistive against leaf hopper (*Amrasca biguttula biguttula*) [32]. Northern spy root stocks of apple is resistive against wooly apple aphid (*Eriosoma lanigerum* Hausm) [33]. ICPL 332 and ICPL 88039 are resistive varieties of pigeon pea to *Helicoverpa armigera*.

IRRI varieties of rice are resistant to plant hoppers and rice borers. Plant resistance and use of natural enemies are key factors to be incorporated in an IPM programs against insect pests [29].

Mechanical or Physical Control

Physical or mechanical method of controlling insect pests is oldest and widely used tactic. These methods include different physical or mechanical practices to control insect pests rather than chemical and manipulation of ecology with biology of insect pests [34].

Tillage

Tillage is the practice to disturb soil surface for number of reasons such as for seed-bed preparation, for integration of organic matter and fertilizer, and for suppression of weeds, diseases and insect pests [35]. These practices play significant role for maintaining population dynamics of natural enemies in relation to pest management [36]. Conservational tillage acts as well to increase natural enemy populations [25, 36]. Carabaeid beetles are more prone to death by tillage operations and particularly entomophagous carabaeid beetles were more sensitive to tillage than herbivorous carabaeid [37, 38].

Many arthropod predators and parasitoids dwelling in litter and foliage are usually destroyed by tillage [39-42] such as, in Canada, cereal leaf beetle (*Oulema melanopus*) might live more without any disturbance by parasitoids because changing in tillage practices killed parasitoids that overwinter in the soil [43].

Traps and Barriers

Traps and barriers are helpful to manage insect pests by interference into their devastating activities and do not allow them to interact the host plant [44]. Early trapping techniques used fail to know about ecology and biology of insect pest but modifications are made now-a-days to improve their efficacy. For instance, Mathematical models are used to enhance trapping ability of traps [45]. For many decades, different stoned, bricked or earthen barriers were used around the field or fruit trees to create hurdle and insect pests were collected around these structures to kill them mechanically and now some baits are used as well which contain attractive food or insect pest pheromone to tackle insect pests [46].

Barriers favor pest management to do not allow insect pests to their feeding and oviposition sites [46]. Many techniques used such as screens, row covers, mulches, trenches, bags, particle barriers and shields to stop activity of insect pests. Insect barriers should have mesh size that omit but does not exclude insect pest enemies [4]. In greenhouse, UV blocking films has well worked against insect pests [48]. Many materials like sand and glass splinters are big sized particles used against termite by blocking their physical movement [49].

Mass trapping along with pheromone does not work economically because of high cost and more labor-intensive regarding their area-wide installation, operation and maintenance [46, 50]. Electric traps in greenhouses and other controlled premises as an attractant-n-kill device usually kill most of the predatory and parasitic insects rather than the targeted biting flies or lepidopteran moths [51].

Transgenic plants

Biological control and host plant resistance, both have key importance for insect pest management. Though, these two methods have a significant influence collectively on IPM [52, 53]. Pest resistant plants can have a variety of positive and negative influences on natural enemies. For instance, phytochemistry of such resistant plants could have a complex interaction with herbivore insect pests and their natural enemies and this tritrophic interaction potentially can interfere with the compatibility among artificial biological control and pest control strategies using induced pest resistance [54-56]. Physiological and chemical makeup of these transgenic plants can disrupt the fitness and behavior of numerous predators and parasitoids of insect pests [55].

Conventional Plant Breeding

In conventionally bred resistant plants, high resistance is major problem as it decreases yield and loss of desirable traits but these drawbacks are recovered on behalf of genetically modified plants by recombinant DNA technology and make them better than traditional insect resistant plants [57]. Albeit, many scientists worked zealously on the interactions between natural enemies and pest-resistant plants for decades [58], but now-a-days most emphasis is on insect-resistant GM (genetically-modified) crops produced by conventional plant breeding to be used as safe, convenient and effective IPM tact [7, 59, 60].

Transgenic Plants

Transgenic plants are alternating source rather than chemicals to rely on for insect pest management. Initially, protein was extracted from *Bacillus thuringiensis* (*Bt*) and incorporated into plants that work as first generation *Bt* transgenic plants but second generation included the *Bt* and non-*Bt* proteins with novel mode of action against insect pests [61]. Transgenic plants act upon insect pests by collaboration with natural enemies [62] and do not have any negative effects on insect pest enemies [63]. Transgenic plants have not or may be of less effect on predators or parasitoids [64]. Romeis *et al*. [65] also revealed that *Bt* transgenic plants have not direct toxic effects on on predators or parasitoids. These findings were in line with findings of Sisterson *et al*. [66] and Whitehouse *et al*. [67].

Chemical control

Chemical control is considered as the most common and efficient insect pest management tactic that most of us strongly rely upon, but indeed has several negative impacts on beneficial organisms and blind and irrational use of these chemicals cause resistance problem. Pesticide products used for pest management in agriculture have been changing so that use of the oldest and most toxic cyclodienes, carbamates and organophosphates is slowly decreasing worldwide [68].

Non-target effects of pesticidal chemicals

Synthetic chemicals meant for controlling pests have been destroying non-targeted fauna including natural enemies' right from their origin [69]. Their lethal effect on target insect pests and other organisms is estimated by determining a median lethal dose (LD_{50}) or median lethal concentration (LC_{50}). Sub-lethal effect of pesticides on natural enemies could be directly on their physiology and behavior. Pesticides include insecticides, herbicides, and fungicides used to control pests and to increase crop yield. However, toxic residues of these chemicals cause severe effects on non-target insects (predators, parasites), wild-life, humans and domestic animals [70-72].

Pest resilience and resistance problem

The term 'resilience' means coming back of something to its original state after some temporary disturbance. Resilience includes how one species respond to other one by competition and predation and its ability to slow down potential growth. A resilient species usually have more strong population than a non-resilient species [73]. In cotton, *Helicoverpa armigera* (Hubner) and *Spodoptera litura* (Fab.) developed resistance against cypermethrin [74] and western flower thrips (*Frankliniella occidentalis*) is a deleterious pest of wide range of crops and resistive against many insect pests [75].

Environmental hazards

Most of insecticides remain in soil as unvolatile undissolvable play a vital role as non-degradable agent and predators such as coccinellids have paid in the presence of these insecticides as these insecticides either are biologically or chemically derived [76]. Pesticides may have different effects on coccinellids and similarly different coccinellids species may have different susceptibility to pesticides. International Organization of Biological Control (IOBC) has developed and recommended standardized techniques for testing the impact of pesticides on natural enemies [78]. To this end, government-imposed standards for evaluation of non-target effects probably have been put into practice in the United States [79]. Goettel *et al*. [80] assessed the effect of numerous biologically based “pesticides” (e.g. bacterial toxins, entomophagous fungi, nematodes) on coccinellids.

A predation of Colorado potato beetle eggs by *Coleomegilla maculata* was reduced when eggs of these beetles were treated ten times with the field dosage of *Bacillus thuringiensis* var. *dan diego*, whereas no reduction was shown from delta-endotoxin induced paralysis [81]. Substantial mortality among young *Hippodamia convergens* larvae are caused by entomophagous fungi (*Metarhizium anisopliae*, *Paecilomyces fumosoroseus*, and two strains of *Beauveria bassiana*), albeit, this predator is not prone to *Nomuraea rileyi* [82]. Likewise, *C. maculata* and *Eriopis connexa* are highly prone to *B. bassiana* [83]. Studies have assessed the insecticidal impact of different pesticides on predaceous coccinellids, and toxicities vary broadly among and within classes of insecticides and coccinellid species [84]. Some of novel insecticides, such as, imidacloprid [85] and abamectin [86], are found very toxic to coccinellid adults and larvae. To mitigate this negative impact, insecticide selection with different dosage and time of application are significantly used to minimize effects on coccinellids while retaining efficacy against pests in alfalfa [87].

Biological control

Biological control is an environment friendly and operative tactic, through which manipulation of natural enemies for reducing insect pest population below economic threshold level. Biological control is a valuable tactic in pest management programs and its initiation in the late nineteenth century when the cottony-cushion scale insect (*Icyera purchasi*) was accidentally introduced from Australia to the United States, where it became a serious threat to the developing citrus industry of California. In one of the first victory of biological control, this pest was successfully managed by the introductions of an Australian lady beetle (*Vedalia cardinalis*) and parasitic fly (*Cryptochaetum iceryae*) [76, 77, 88].

Components of a biological control

There are following components of biological control as briefed below;

Entomopathogenic organisms

Entomopathogenic microorganisms which are being used as bio-control agents against different insect pests include; fungi, nematodes, bacteria and viruses. These pathogenic organisms tend to control populations of many arthropods naturally by producing different kinds of diseases in them. Many entomopathogens have been used as classical bio-control agents for alien and natural insect pests and could be mass reared and applied to insect pest populations [89].

Entomopathogenic bacteria can employ considerable pressure to decrease insect pest population [90] and among these bacteria, *Bacillus thuringiensis* (*Bt*) is a most efficient [57] spore forming bacterium which cause crystallization into gut of many insect pests of lepidopteran, dipteran and coleopteran. Generally, about 70 sub-species of *Bt* are known worldwide which infect many of lepidopteran, dipteran and coleopteran [91]. Sources of these *Bacilli* are varied; got from dead insects and from soil. A strain, *B. thuringiensis var. San Diego* is effective against Colorado potato beetle but showed no response against corn rootworms. Similarly, in 1975, environmental protection agency of USA registered first virus of *Baculo* genus for commercial use on cotton, which is a nucleo-polyhedro virus of maize borer, *Helicoverpa zea.*

Entomopathogenic viruses like other natural enemies can exert considerable control on insect pest populations belonging to Lepidoptera and Hymenoptera [92]. Baculoviridae family shows greatest interest in biological control program as it has very important strains of baculo virus [93, 94].

Entomopathogenic fungi have ability to keep check and balance of natural insect pests and among all other pathogenic organisms. These fungi have utmost parasitic ability and cause severe epizootics in pest populations. Approximately 750 species of entomopathogenic fungi are known so far which parasitize arthropod pests [94], and these identified species belong to two main orders which are Entomophthorales and Hypocreales [95]. Entomophthorales occur in the phylum Zygomycota and include genera such as Pandora, Entomophthora and Conidiobolus and cause natural epizootics in insect pests [96], and they can be used for pest control by being applied to the field. Isolates of *Neozygites floridana* from S. America are being investigated for classical biological control of the cassava green mite *Mononychellus tanajoa*, a major alien pest of cassava in Africa [97].

The Hypocreales occurs in the phylum Ascomycotina and members are called anamorphic fungi because these reproduce asexually. Most important genera of anamorphic-entomopathogenic fungi are *Beauveria*, *Isaria*, *Metarhizium* and *Lecanicillium* [98]. These fungi are mass reared to be used as bio-pesticides, very against to sap feeding insect pests, like aphids and whiteflies with no harmful effects on insect pest enemies and on human health. But there are some limitations of using them as their manufacture cost is higher than synthetic chemicals and can be affected badly by some environmental variations. Vertalec and Mycotal are two bio-pesticides based on fungus *Lecanicillium* for control of glasshouse aphid and whitefly respectively [99].

Moreover, entomopathogenic nematodes are tremendously used and have ability to infest their target insect pests perfectly with diverse association with symbiotic bacteria that make them significant for bio-control program [94]. More than 30 families of nematodes exist to parasitize host insects [100] but steinernematids and heterorhabditids are two major families which are used most for control of insect pests by penetrating themselves into host body through piercing the cuticle or enter by natural openings then symbiotic bacteria multiply rapidly and break down the insect body that ultimately cause death by septicaemia [101]. In UK, almost 60 commercial products of nematode bio-pesticides (Koppert, Biobest, and Syngenta Bioline etc) are available that work against many insect pests like vine weevil [102, 103]. Moist condition favors growth of nematodes but adverse environment also effect badly on their activity like other natural enemies but *Steinernema kraussei*, a nematode strain which actively work at low temperature and controls vine weevil in start of season.

There is a great potential for their integration and incorporation in IPM programs against different insect pests because unlike synthetic pesticides, entomopathogenic organisms are environment friendly and have minimum non-target effects [104].

Parasitoids

A parasitoid is an organism mostly an insect or other invertebrate that is parasitic only in its immature stage when it grows either as endoparasitic or ectoparasitic from eggs which are laid inside or near target host. Adult parasitoid is usually free living and generally feeds on pollen, nectar and body fluid of host [105]. Different life stages of insect pests are prone to be attacked and parasitized by different species of parasitoids. *Trichogramma* wasp, for instance, is an egg parasitoids and *Cotesia glomerata* belonged to Braconidae, which is larval parasitoid [106]. According to an estimate, about 10% of total insect species are parasitic on insects or other organism and they belong to about 86 families mainly from Hymenoptera (Braconidae, Chalcidae, Eulophidae, Trichogrammatidae, Aphidiidae), Diptera (Tachindiae, Phoridae), Strepsiptera (Callipharixenidae, Stylopidae), Coleoptera (Passandridae) and Lepidoptera (Epipyropidae).

Predators

Predators are very efficiently used bio-control agents in pest management programs since past. Firstly, predators were introduced from china as early as 900 A.D. when Chinese farmers used to introduce ants (*Oecophylla smaragdina* F.) on trees and in their citrus orchards to protect them from insect pests infestation [77, 107] and in Yemen, date growers used these ants to suppress the activity of phytophagous ants [76]. In 19th century, business of ladybugs was at zenith of its fame [77].

In last 18th, cottony cushion scale was accidentally introduced from Australia to California and growers found it worst in the orange groves while sucking plant juices and plant unable to produced fruits [108].

Cottony cushion scale became worst pest in California than at Australia because there was some resistive force in Australia that kept their quantity below, which need to be introduced at California, then in 1888, a scientist named Albert Koebele discovered an Australian lady bug (*Rodolia cardinalis*) eating cottony cushion scale in a garden in Adelaide which were introduced to California orange groves but American lady bugs didn't look to feed on these scales vigorously as Australian lady bug did. But within a year, most of the cottony cushion scale insects were eaten and the orange groves and their crop were saved [108, 109].

Predator-prey association

Understanding predator-prey relationship helps in ecological studies. Prey abominates predator whereas predator loves prey. Predation involves relationship between predator's foraging ability and prey's availability [110]. Most of predatory insects which attack and feed on other insects belong to the orders Odonata, Mantodea, Neuroptera and Mecoptera [111].

Predatory insects are amenable organisms in field and laboratory studies of predator-prey interactions as they are unresponsive to human attention, easy to manipulate and may have several generations per year and show a range of predatory and defensive strategies and life histories. Studies of predator-prey interaction provide basis to biological control practices to manage insect pests. Morphological features of predators modified for capturing prey and accused prey might show defensive attitude towards predators [111].

Coccinellid beetles

Coccinellids, also known as ladybird beetles, belong to Coccinellidae family of insect order Coleoptera. These beetles not only have defoliating activity but primarily 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) [112, 113].

There have been about 6000 species of coccinellid beetles known worldwide [114]. The family Coccinellidae is placed in the superfamily Cucujoidea, series Cucujiformia within the suborder Polyphaga and order Coleoptera. The sub-families are Coccinellinae, Chilocorine, Scymninae, Coccidulinae, Sticholotidinae and Epilachninae. Out of these, five subfamilies are predacious and one of them Epilachninae is phytophagous in nature. All of these subfamilies are distributed worldwide [115].

Brief biology and ecology

The life history of ladybirds revealed from eggs to adult, ladybirds produce larvae which undergo 4 instars before pupation and form adults. The color of larval stages varies among the species [116]. Freshly hatched larvae are grayish or black with yellow, orange and red color spots on dorsal side of body. Last larval instar pupates while attaching to a leaf, stem or other surfaces. The pupae of aphid-feeding ladybird beetles are of pale color with black spots on dorsal side of body. Beetles of certain species are entirely yellowish white after emergence. Marking occurs gradually and beetles become red or dark. Adults look beautiful due to their bright color patterns particularly on their elytra. 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 [117]. 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. 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. Haemolymph of ladybird beetles has many alkaloids, so claimed for repulsive activity and bright color pattern also acts as aposematic; a warning for predators that not to see as meal [116].

Integration of coccinellid beetles in IPM programs

Coccinellid beetles have been successfully deployed in different integrated management programs against a wide variety of insect pests on different crops with a mixed rate of success. Few studies have been summarized below (Table 1);

Table 1: List of integrated coccinellid species prey on different insect pest species from field and laboratory

Coccinellid species	Target prey	Targeted crop	References
Brumoides suturalis	White-backed plant-hopper	Rice	Garg and Sethi [118]
Ceratomegilla maculate	Rice delphacid	Rice	King and Saunders [119]
Coccinella arcuata	Brown plant-hopper	Rice	Abraham and Mathew [120]
Coccinella septempunctata	Smaller brown plant-hopper	Rice	Harpaz [121]
Coccinella septempunctata	Mustard aphid	rapeseed and mustard	Mathur [122]
Coelophora inaequalis	Sugarcane leaf-hopper	*sugar cane*	Swezey [123]
Harmonia sp.	Brown plant-hopper	Rice	Dyck and Orlido [124]
Verania sp.	Brown plant-hopper	Rice	Dyck and Orlido [124]
Hippodamia tredecimpunctata	Brown plant-hopper	Rice	Lei and Wang [125]
Illeis Indica	Corn plant-hopper	Corn	Fisk *et al.* [126]
Synharmonia octomaculata	Brown plant-hopper	Rice	Ooi [127]
Coccinella undecimpunctata	Aphids	In vitro	Farag *et al.* [128]

Adalia bipunctata	Aphids	In vitro	Kariluoto *et al.* [129]
Coccinella septempunctata	Bean aphid	In vitro	Mahyoub *et al.* [130]
Adalia bipunctata	Aphids	In vitro	Bonte *et al.* [131]
Chilocorus nigritus	Scale insects	In vitro	Hattingh and Samways [132]
Cleobora mellyi	Eucalyptus tortoise beetle	Eucalyptus	Bain *et al.* [133]
Clitostethus arcuatus	Whiteflies	In vitro	Mota *et al.* [134]
Clitostethus arcuatus	Whiteflies	In vitro	Yazdani and Zarabi [135]
Harmonia axyridis	Aphid	grasses	Osawa [136]
Delphastus catalinae	Whiteflies	Cotton	Legaspi *el al.* [137]
Diomus terminates	Yellow Sugarcane Aphid	sugarcane	Auad *et al.* [138]
Eriopis connexa	Corn leaf aphid	Corn	Silva *et al.* [139]
Hippodamia convergens	Mediterranean flour moth	In vitro	Kato *et al.* [140]
Menochilus sexmaculatus	Aphids	In vitro	Khan and Khan [141]
Nephus includens	Mealybugs	In vitro	Canhilal *et al*. [142]
Propylea dissecta	Aphids	In vitro	Omkar [143]

Conclusive remarks

The uses of biological agents is one and only control measure in pest management programs that is less laborious, more environment-friendly and more effective without any harmful effects on non-target organisms and coccinellid beetles have a tremendous potential in this regard.

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