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BIOLOGICAL
Control of Insect and Weed Pests

Edited by
Jaime A Cuervo-Parra, Mario Ramírez-Lepe
and Teresa Romero Cortes

Biological Control of Insect and Weed Pests

Edited by: Teresa Romero Cortes

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Preface

Biological control agents are the instruments for biological control which is the technique of defending crops who is born from the study of the equilibrium present in nature between the harmful organisms and their natural antagonists. Where antagonists are bred in large quantities to be distributed after over crops, in order to reduce populations of pest insects. Therefore, the present work is a review on biological control of insects and its importance for the management of harmful pests in agriculture. Aspects of vital importance as the attributes of natural enemies, importance of taxonomy to biological control, mass rearing of natural enemies and their quality control and biological control currently in the world are some of the topics covered in this bibliographical review.Even today there are many valuable lands lost to weeds. Some weeds are just hard to kill and others are easily to kill, grow on lands too low in value or too inaccessible for control by traditional methods. Classical biological control consists of the introduction and release of exotic insects, mites, or pathogens that help achieve a permanent control, which is the predominant method in biological control of weeds. Worldwide weeds in natural ecosystems are increasingly becoming targets for biocontrol. Discussion continues on agent selection, but host-specificity testing is well developed and reliable. Post-release evaluation of impact is increasing, both on the target weed and on non-target plants. On the other hand, control of aquatic weeds has been a notable success. Alien plant problems are increasing worldwide, and biocontrol offers the only safe, economic, and environmentally sustainable solution.

Signature

About Author

Dr. Teresa Romero Cortes is a graduate student from the faculty of Bioanalysis of the Universidad Veracruzana, later she earned an Mastery in Biochemical Engineering and a PhD in Food Science from the Instituto Tecnológico de Veracruz. She currently serves as a research professor at the Universidad Autónoma del Estado de Hidalgo, Apan campus in which she has participated in the creation of two educational programs of national importance. She has the desirable profile recognition by the Secretaria de Educación Pública (SEP) and recognition by the Sistema Nacional de Investigadores ("National Research System", SNI). Is member of the research in genetics and bioprocess engineering. His research interests are focused on the general microbiology, predictive microbiology, molecular biology, microbial biotechnology and the effect of cold storage on the flexibility of the cuticle ("mixiote") of pulque maguey (*Agave* sp.).

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Introduction to the eBook

The chapters in this eBook include topics from the historical background and definitions of biological control, approaches to biological control, major types of organisms targeted for biological control, types of natural enemies, and insects in the biological control of weeds. On these topics, a compilation of all the relevant information covered in each topic and subtopic was held. References are provided for readers who wish to delve deeper into some of the issues. I have edited and reviewed the content and style of each chapter in order to unify the voice of the entire text.

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Teresa Romero Cortes[1]*, Mario Ramírez-Lepe[2] and Jaime A Cuervo-Parra[1]

[1]Escuela Superior de Apan, Universidad Autónoma del Estado de Hidalgo, Carretera Apan-Calpulalpan, Km 8, Chimalpa Tlalayote s/n, Colony Chimalpa, Apan, Hgo., Mexico.

[2]Unidad de Investigación y Desarrollo en Alimentos, Instituto Tecnológico de Veracruz, Av. Miguel Angel de Quevedo no. 2779. Colony Formando Hogar. Veracruz, Ver. Mexico.

.

***Corresponding author:** Teresa Romero Cortes, Escuela Superior de Apan, Universidad Autónoma del Estado de Hidalgo, Carretera Apan-Calpulalpan, Km 8, Chimalpa Tlalayote s/n, Colony Chimalpa, Apan, Hgo., Mexico, Tel: (771) 7172000 ext. 5805; E-mail: tromerocortes@gmail.com

Abstract

Biological control agents are the instruments for biological control which is the technique of defending crops who is born from the study of the equilibrium present in nature between the harmful organisms and their natural antagonists. Where antagonists are bred in large quantities to be distributed after over crops, in order to reduce populations of pest insects. Therefore, the present work is a review on biological control of insects and its importance for the management of harmful pests in agriculture. Aspects of vital importance as the attributes of natural enemies, importance of taxonomy to biological control, mass rearing of natural enemies and their quality control and biological control currently in the world are some of the topics covered in this bibliographical review.

Even today there are many valuable lands lost to weeds. Some weeds are just hard to kill and others are easily to kill, grow on lands too low in value or too inaccessible for control by traditional methods. Classical biological control consists of the introduction and release of exotic insects, mites, or pathogens that help achieve a permanent control, which is the predominant method in biological control of weeds. Worldwide weeds in natural ecosystems are increasingly becoming targets for biocontrol. Discussion continues on agent selection, but host-specificity testing is well developed and reliable. Post-release evaluation of impact is increasing, both on the target weed and on non-target plants. On the other hand, control of aquatic weeds has been a notable success. Alien plant problems are increasing worldwide, and biocontrol offers the only safe, economic, and environmentally sustainable solution.

Keywords: Biological Control, Insect Pests, Natural Enemies, Parasitoids, Predators and Weeds.

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Introduction

An estimated one third of global agricultural production, valued at several billion dollars is destroyed annually by over 20,000 species of field and storage pests [1]. Yield decline due to pests reaches 20-30% in most crops, despite the substantial increase in the use of pesticides (about 500 thousand tons globally active ingredient) this is a symptom of the environmental crisis that affects the agriculture [2]. Other sources report that the losses in agricultural production worldwide by pests fluctuate between 20 and 40% and at least 10% of the crops were destroyed by rodents and insects in the storage locations [3]. Therefore, the extent of damage varies according to region, season, crop and pest as a causal factor, causing economic losses of billions of dollars per year [4]. For example, in Mexico an area of 22,136,741.58 hectares is planted with more than 200 cultivated species [5] and about 95,025 tons of pesticides per year are used [6]. The insecticides used are characterized by being wide spectrum and be toxic, affecting human health, pollute underground streams, act negatively on the different species of beneficial insects, which include natural enemies such as parasitoids, predators and pollinators [3].

The facility provided by the use of chemicals synthesis products to control pests and diseases has led to the consolidation of farming methods based on the widespread use of these inputs. Along with this practice there have appeared a number of problems that threaten both the sustainability and quality of crops and the health of people and natural systems [7]. In addition to this, human population growth brings simultaneous burdens of sustaining a steady food supply; these include preventing losses from pests, dealing with increased human global travel, which in turn intensifies opportunities for the establishment of non-endemic pests into new ecosystems, and addressing global climate change that potentially will shift pest distributions into new areas [8]. On the other hand, modern agricultural practices affect negatively the natural pests enemies, which in turn not found the necessary conditions to reproduce itself and thus be able to biologically suppress the pests in monocultures [2]. Therefore, ignorance and misuse of pesticides affects the whole environment, specifically wildlife species, causing an imbalance in the ecosystem, together with the lack of technical knowledge of the applications of agrochemicals such as dose, frequency of application, management groups and chemical toxicology, site of action of pesticides and spray quality as calibration becomes a pollution problem [9].

To curb this trend, the social sectors, scientific and political demand for agricultural professionals a change in the pest handling directed towards more sustainable strategies [10]. These concerns drive the discovery and development of alternatives to chemical control of plant pathogens, weeds, and insect pests [8]. One of these alternatives is the biological control. The use of biological control is a fundamental tactic for pest suppression within an effective integrated pest management program [11].

This approach for pest control is the use of natural enemies and control microorganism the populations of the pest organism [12]. Biological control, is a technique which have ancient records. For example, in 2000 BC in Egypt, cats were used to control rodent populations. Furthermore, many centuries ago, Chinese farmers observed that ants (*Oecophylla smaragdina* Fabricius) were helping them to control insect pests in their citrus orchards by feeding on caterpillars [11], beetles [13], and leaf-feeding bugs [14]. Farmers realized that when they collect the papery nests of these ants from trees in the countryside and move them to their orchards improved control of some orchard pests. These efforts to increase the number of ants in orchards and increase their efficiency as predators represents the first recorded appearance biological control of insects [14].

Although new ideas find a significant difficulty to be accepted, already in the early twenty-first century, most researchers have assumed that the plant communities that specialize in order to obtain products for human consumption, are more susceptible to damage caused by different types of insects. In general, the more you has been amended one plant community, more abundant and serious would be the pest [15]. The monocultures compounds generally of genetically similar or identical plants that have been selected for their greater palatability, are highly vulnerable to attack from herbivorous adapted as insects [16]. Furthermore, we now know that many practices that increase crop yields through the use of nitrogenous fertilizers, nonselective insecticides treatments, and so on, what really tend to cause is a remarkable increase of the pests having a strong incidence on populations of natural enemies of these insects to be controlled [17].

Ecological stability and self-regulation characteristics of natural ecosystems are lost when man simplifies natural communities through breaking the fragile tissue interactions at the community level. One of the most important reasons to restore and/or maintain biodiversity in agriculture, it is because biodiversity provides a wide range of ecological services. One of these services is the regulation of the abundance of undesirable organisms through predation, parasitism and competition [15]. Probably each insect population in the wild is attacked in some measure by one or more natural enemies. Thus, predators, parasitoids and pathogens act as natural control agents which, when are properly managed, can determine the regulation of herbivore populations in a particular agroecosystem. This regulation has been called biological control and has been defined by DeBach in 1964 as the action of parasitoids predators or pathogens to keep the population density of a pest organism at a lower average than would occur in their absence [18]. Depending on how you practice, biological control can be self-sustaining and differs from other forms of control because it acts depending on the density of the pest population. In this way the natural enemies of insects increase in intensity and destroy most of the pest population to the extent that it increases in density and vice versa [19]. In this way, biological control is an ecological and sustainable tool, that operated well prevents biological imbalances reported by the improper use and handling of pesticides [3].

Historical Background and Definitions

The term "biological control" was first used in 1919 by A.H.S. Smith to explain the use of natural enemies (Introduced Whether manipulated or Otherwise) for the control of insect pests [20]. Then, the term Integrated Pest Management has, more often than not, been identified with entomologists [8]. First the term was used as "integrated control" to describe the potential for integration of chemical and biological control tactics [21]. Yet from a historical view, the concept of integrating chemical control with other tactics was proposed much earlier in the year 1939 [22]. Subsequently, DeBach in 1964 redefined the term and distinguished natural control from biological control [18].

Many definitions of biological control have been published in literature since the term was first used by A.H.S. Smith in 1919 [19,23-27]. In its strictest sense, biological control consists in the use of beneficial organisms to reduce the relative abundance of the harmful organisms which are causing damage to their host [8].

The natural control is the maintenance of a population density of more or less fluctuating organism within certain definable limits over a period of time by the actions of abiotic and/or biotic factors. Moreover, biological control is the action of parasites, predators or pathogens on the maintenance of population densities of other organisms at a lower average than would occur in its absence [20]. Subsequently, other authors modified the terms referring to applied biological control as the manipulation of natural enemies by human to control pests; and natural biological control as that control that occurs without human intervention [28].

Applied biological control can be divided into 3 main categories: a) classical biological control, where the control of a pest species is done by introducing natural enemies; b) augmentation of natural enemies, where measures are taken to increase the populations or the beneficial effects of natural enemies; and c) conservation of natural enemies, where the necessary actions are taken to protect and maintain populations of natural enemies of the organisms to be controlled [20].

Classical biological control consists of re-establishing the balance of nature in a country in which an introduced organism has become a pest, and the organisms that will reduce the population of this pest to acceptable levels are introduced from their country of origin, after being carefully evaluated for host specificity [29].

Subsequent definitions were expanded by the "non-biological control purists" to include factors such as host plant resistance, auto-sterilization, genetic manipulation of species (including genetic engineering), cultural controls, unconventional insecticides (insect growth regulators, etc.), and transgenic plants. In this case these methods are not considered as "biological control". Biological control will be discussed as the science that deals with the role that natural enemies play in regulating the amount of their hosts, especially as applied to animal or plant pests [20]. Furthermore, integrating multiple non-chemical tactics to control a pest has been a cornerstone of the discipline of plant pathology throughout much of its early history [30].

Approaches to Biological Control

Biological control has several advantages as it is focused to a particular pest specie, while the pest population is kept for many years without causing economic damage. In addition, long-term, biological control is one of the most inexpensive, safe, selective and efficient methods for controlling pests [12].

Natural enemies have been used in the management of insect pests for many centuries. However, this last 100 years have seen a dramatic increase in its use, as well as our understanding of how they can best be handled as part of effective, safe, pest management systems [31]. Recent advances in molecular systematic are shedding new light on classification of groups of beneficial insects such as the Hymenoptera [32]. Recent advances in the study of beneficial organism behavior [33,34] and reproductive biology [35] are revealing surprising complexities in the life histories of these organisms. Understanding this complexity should lead to potential new methods for their manipulation [31].

Some of the advantages of biological control are that the biological control agent is specific to the pest and represents a little or no adverse effects on non-target organisms; its implementation is feasible in regions (national parks, forests or grasslands), where other methods are not applicable; once established, the control agents concerned perpetuate themselves without the need for further introductions; any action of farmers and other beneficiaries, except is required to avoid unnecessary use of pesticides and, where appropriate, to selectively use or reduced use of chemicals spectrum; all producers benefit and the cost/benefit ratio is very high compared to most other control methods [29].

The use of biological control to manage pests is divided into three types of approaches: importation, augmentation and conservation. When an insect pest is accidentally introduced in an area where not existed before it becomes a problem because it lacks the presence of their natural enemies that would maintain under control its populations. In these cases is where the importation and permanent establishment of their natural enemies is required to control pest populations [11]. On the other hand, augmentation is an attempt to reduce the population of a pest to non-economic levels by temporarily increasing the number of natural enemies in an area through periodic releases. After entering these natural enemies, they will seek and attack the pest [11].

Lastly, conservation, is responsible for the protection of natural enemies already present in the area. Therefore, conservation, an attempt to manipulate the environment or agricultural practices with this to protect natural enemies or provide the necessary resources so that they can survive and form populations to levels where they can manage the pest and prevent blocks causing economic damage to crops [11].

Both natural and applied biological control tactics are important strategies in successful management of pest populations. After nearly two decades of intensive teaching and field level training, farmers have understood the value of biological control. Having realized that most of the synthetic chemicals decimate the beneficial parasitoids and predators, the farmers have started using selective pesticides along with biological control agents and botanical pesticides like neem products [36].

Importation Biological Control

The importation biological control is the oldest of the three approach is hence its alternative name “classic” is derived [8]. The first reports from which have registry dating back a century implemented for the biological control of cottony cushion scale in California citrus plants after importation of the vedalia beetle [37]. The classical approach consists in the reestablishment of interspecific interactions between pests and their natural enemies which occur in the pest endemic range [38]. Moreover, importation biological control has been used against many noxious pests in many countries with varying degree of success [39].

Although there are few reported cases of ecological or economic damage that has been the introduction of biological control agents in environments alien to home, exists by the part of the population some uncertainty regarding the effect that importation biological control may have on the local wildlife [40]. Therefore, it is necessary for researchers working with biological importation, to minimize risks showing evidence that natural enemies of pests that will enter in the environment will not cause damage to crops, humans or the ecosystem [8].

Augmentation Biological Control

With the augmentation of biological control is to be increase in number the proportion existing between pests and their natural enemies with the purpose of increasing the death of the first [8]. In other words, the goal of augmentation biological control is to temporarily increase the number of natural enemies and therefore the level of biological control of the target pest [14].

To cover this objective the biological control agents are typically propagated and maintained in large quantities to inoculate insectary or swamping in the areas of interest [41,42]. In the releases into the inoculations involve a small number of natural enemies back repeatedly, typically when pest populations are small or to the beginning life cycle or season. Moreover, the flood involves the release of a large number of natural enemies back repeatedly through the growth cycle or season. In these two types of releases, the goal is to cause as much damage to the populations of pests by synchronizing the natural life cycles of pests enemies [8].

Augmentation biological control has been used successfully against key pests of field and greenhouse crops [8]. A well-known example of this type of biological control is the use of the parasitoid, *Encarsia formosa* for control of greenhouse whitefly [43]. In fact, augmentation plays an important role in greenhouse production , especially in Europe, and many natural enemies are commercially available for control of perennial greenhouse pests such as spider mites, aphids, scales, and whiteflies [44,45].

Although augmentation has done well in the greenhouse conditions, in contrast, a critical review of augmentation biological control of in field crops revealed that augmentation was typically less effective and more expensive than conventional control made with pesticide [46].

The movement of ants from the countryside into the orchards made by the Chinese farmers many centuries ago to control insect pests, is an example of augmentation biological control [14].

Conservation Biological Control

Conservation biological control involves any practice that increases the colonization, establishment, reproduction and survival of native organisms or natural enemies already established [47].

With the conservation of natural enemies is possible to improve the effectiveness of natural enemies through the implementation of agricultural and gardening practices that provide the necessary resources for their survival and protect them from toxins and other adverse conditions. These conservation practices benefit all natural enemies, whether they are natives, successfully established through classical biological control, or released for augmentation biological control [14].

Conservation biological control can be approached from two ways: modifying pesticide use and manipulating the growing environment in favor of natural enemies [8]. Conservation practices have proven effective in a wide variety of growing situations ranging from small garden plots to large fields, agricultural to urban environments, and commercial to private settings [48-50].

Back to the example of Chinese farmers again, the use of runways between trees increased the ants' access to prey while keeping them away from potential harm on the orchard floor, being this an example of conservation biological control [14].

Major Types of Organisms Targeted For Biological Control

Biological control was first used to control insects, mites and weeds [18,51-55] but then the application of the method was more open and other animals, like vertebrates and invertebrates were considered elements of biological control [56-62]. In general terms, a pest is any organism (microbe, plant or animal) that is a nuisance or causes injury to humans, domestic animals, crops, stored products, buildings or possessions [14].

Insect pests are a major constraint to increased global production of food and fiber [1]. There are approximately 90,000 described species of insects in North America and over 750,000 worldwide. Moreover, worldwide, entomologists estimate that there may be 4-6 million species of insects, which means that most species have not yet been discovered, identified, named and studied [14]. Despite this incredible diversity, only a small percentage of species of insects cause damage to humans and domestic animals or cause damage to our crops or possessions. The rest are beneficial to humans or the environment, or have no recognizable significant impact, either positive or negative [14].

Agricultural pests include the microorganisms that cause plant diseases (bacteria, viruses, phytoplasmas and fungi), plant-parasitic nematodes, weeds, certain vertebrate animals (deer, birds, rodents), mollusks (snails and slugs), certain arthropods (insects, mites and millipedes), and occasionally other organisms [14]. Insect species typical of a place that achieve high levels of damage to local crops are known as native pests and those that originate in another geographic location as exotics [12]. Moreover, the agents used for biological control including arthropod natural enemies, entomopathogens (bacteria, nematode, virus, and fungus), plant-derived insecticides and insect hormones are receiving significant interest as alternatives to chemical pesticides and as key components of integrated pest management system [1].

Arthropod Pests

Among the invertebrates, arthropods are a taxonomic group very evolutionarily successful with a length of at least 540 million years [63,64]. Because it has reached large number of species, when compared with other taxa, as they are widely adapted to almost all habitats and microhabitats, plus they are remarkably diverse in thousands of families and tribes. They constitute 85% of the world fauna and represent 65% of the species [65]. Estimates of the number of arthropod species in the world vary from just over one million [66,67], which are the most conservative figures, to about 30 million or more, only to insects in the most extreme estimates [68]. Other estimates place about 70% of the global species diversity are represented by arthropods [63].

Insects

Insects are the most diverse group of organisms in the world, around 5000 species are pests that feed on crops, houses or transmit some type of diseases [68]. The management of insect pests has often been considered to be reached by simple technological solutions; however, the most durable solutions to insect pests that have been developed, are those that seriously consider the ecology of the pests and integrate the solution into the pest's ecology like biological control [69].

Pest insects are the most common type of organisms for which biological control has been used [70]. About 543 species of insects around the world have been controlled through roughly 1,200 programs of biological control introductions [71] and many have done through programs of conservation and augmentation of natural enemies. These programs have included the control of insects belonging to the most important orders of herbivores, such as Homoptera, Diptera, Hymenoptera, Coleoptera, Lepidoptera and other groups [12]. Homoptera has been the order against which the biological control through introduction of natural enemies has been more successful [72].

One of the reasons of the increase of insect populations at a certain culture is the imbalance that has in his natural habitat [73]. In addition, the large number of species in these groups that are important pests in many crops and the great diversity of parasitoids and predators that hold, are significant factors to keep these insects densities below the damage threshold [12].

Studies of natural pathogens for termite biological control began in 1965 [74]. Most of these studies focused on the fungus *Metarhizium anisopliae* (Metschnikoff) Sorokin and *Beauveria bassiana* (Balsamo) Vuillemin [75-77], which have a wide distribution in soil with host ranges very broad [78]. Their effectiveness in the control of termites has been tested at laboratory level; however, its application in the field has not been successful [79-81]. The main reason why pathogens failed to control termites in field conditions is due to the social behavior of these Isoptera, which includes grooming between nest mates [76]. Other factors that may be inhibiting the growth of pathogens in termite nests or galleries are carbon dioxide, the high content of naphthalene and secretions of termites, which causes that the control by pathogens not be successful under field conditions [82,83]. For these reasons, biological control of termites using these pathogenic fungi has been generally regarded as unviable [78]. However, because of the removal from the market of some potent chemical termiticides, has renewed interest in the use of biological control agents to control termites [84-88].

Species like *Rhynchophorus palmarun* cause considerable crop losses in coconut due to direct damage caused on palm plants, as they carrier in its gut the nematode *Radinaphelenchus cocophilus*, causal agent of the red ring disease of coconut [89]. In addition to the disease spread to the palms, the larval stage of this beetle drill the tissues of the stipe and buds of trees causing internal rot of the meristem, which gives rise to progressive wilting and plant death [47]. Among the methods of control burning dead plants is performed to remove all larvae that they contain and disinfect tools used for pruning, in order to prevent the spread of the disease [89].

Many Orthopteran species have been part of biological control programs. Within these may be mentioned the western lubber grasshopper *Brachystola magna* [90], *Boopedun nubilum* [91] and *Taeniopoda eques* [92].

The grasshopper pest is found in many countries of the world in which they cause losses in production due to their feed habits. Among the most common control methods are chemical insecticides [93] and biological control using fungi. Furthermore, predators and parasitoids have a significant impact on grasshopper populations, as these are attacked by predators and parasites, such as birds, parasitoids, nematodes and microorganisms [94]. Among them may be mentioned, *Metarhizium anisopliae* var. *acridium* and *Entomophaga grylli*; the bacterium *Coccobacillus acridiorum*; the protozoan *Nosema locustae*; viruses of the genus *Entomopoxvirus*, as well as various parasites and predators [95].

Mites

Several families of mites have been subject of biological control efforts. These include dust mites (rust mites) of the Europhydae family [96-98], mites of the Tarsonemidae family [98] and the most known as the red mite and other pests of the Tetranychidae family [99].

Key actions include the introduction of predatory mites primarily Phytoseidae and generalist as Coccinellidae, conservation of native predatory mites and augmentative releases of predatory mites of laboratory reared [99].

Other Invertebrates

After insects and mites, snails are a group of invertebrates against which biological control programs have turned their attention. This is mainly due to its activity as herbivores, because they cause damage to crops, or by his medical importance because they are intermediate hosts of pathogens that cause disease in humans and domestic animals [12,60,100].

The biological control efforts against other types of invertebrates have been scarce [12]. Among the few existing investigations, may be mentioned the introduction of the parasitoid poisonous spider eggs *Latrodectus mactans* [52] in Hawaii, and the importation into Australia of the parasitic fly *Pelidnoptera nigripennis* to control the specie of millipedes *Ommatoiulus moreletti* [101].

Weed species

Plants of different taxonomic groups have become a weed in a great variety of habitats, including forests, agricultural areas and native ecosystems terrestrial and aquatic [12]. At least 116 plant species distributed in 34 families have been used in biological control programs, through the introduction of invertebrate herbivores or plant pathogens [55]. For example, the use of predatory species, including insects and triploid grass carp (*Ctenopharyngodon idella*), as biological control agents has been developed for management of both aquatic and terrestrial plants [56].

On the other hand, about 47% of weed species studied belong to three families: Asteraceae, Cactaceae and Mimosaceae. However, other families contain individual species of great economic importance that have also been the focus of intense efforts, among them are: Clusiaceae (*Hypericum perforatum*, St John's wort), Salviniaceae (*Salvinia molesta*, water fern) and Verbenaceae (*Lantana camara*, Lantana) [12].

The success of the programs of biological control of weeds using herbivores insects as biocontrol agents is to maintain populations of herbivores at levels sufficient to cause damage to the host plant [102]. However, most herbivore species persist at low densities at which they do little damage to the host [103].

The question of what maintains most herbivorous insect species at levels far below those at which they deplete their resources has been keeping population ecologists occupied for decades. Whereas some authors have emphasized the importance of external factors such as natural enemies or climatic conditions; on the other hand, others have sought the key to population dynamics in the characteristics of the species themselves [102]. Studies comparing outbreak and non-outbreak herbivores have revealed a variety of life-history traits that are associated with a tendency to erupt [104-107]. Probably the most striking pattern to emerge from these studies is a consistent association between outbreaking and gregarious behavior [104,106,108-110]. Biological control has not been commonly applied to pasture, however, there are some possibilities for biological control of some grass species that are considered weeds [12].

Vertebrates

As regards to wild vertebrate populations, such as rats, pigs, goats, sheep, rabbits, and others, are considered major pests in some regions, especially in meadows, forests and nature conservation areas. Although, many of these species, however, are desirable in other contexts [12].

The biological control efforts directed at vertebrates should use specific enough agents to thereby protect other vertebrates and thus prevent larger problems. Such projects can be carried out only in areas where the conflict between the need to control wild populations and of protecting domestic populations of the same species do not exist, or where efforts to carry out a program of biological control have been judged positively [12].

Vertebrate biological control methods include the introduction of pathogens in a narrow host range. For example, using genetically modified vertebrates pathogens such as myxomatosis virus, in rabbit. This virus infects females, which develop antibodies against the sperm of their own species, thus preventing reproduction [111,112].

Another method includes modifying habitats to increase native predators such as the use of perches for raptors [12].

Types of Natural Enemies

Originally, natural enemies were used in classical biological control where the introduction and permanent establishment of an alien species for control or suppression, long-term from a population of a pest was performed. These natural enemies are collected and sent to the country or place where the pest is exotic and has no enemies, so it has become a serious problem [12].

Exploration of the relationships between natural enemy biodiversity and the suppression of arthropod herbivores is of crucial importance in our comprehension of the value of biodiversity and its impact on ecosystem services [113]. For that reason, successful biological control programs are based not only in the identification of the pest and their natural enemies involved, but also on a thorough understanding of their life cycles and other biological characteristics [14].

Therefore, natural enemies of insect pest play a key role in the process of reduction of the levels of pest populations below those causing economic injury [36]. However, What are natural enemies? natural enemies are an organism that control some insect pest, and thus help regulate pest densities in nature, making cropping systems sustainable [114]. Natural enemies of insect pest fall basically into three types: parasitoids, predators and pathogens [11]. For the successful implementation of all forms of biological control requires familiarity with the natural enemies of pests to control its benefits and understand how they fit into an overall pest control program [14].

In the literature, a large number of studies have reported evidences for each of these possible effects of the biological control [115-120]. Other authors, in 2009, in order to synthesize the state of the art on the relationships between natural enemy biodiversity and herbivore mortality in different ecosystems, performed a meta-analysis on this topic [121]. Their results highlight the importance to take natural enemy biodiversity into account in agricultural systems when interested in insect pest control [113].

Parasitoids, Predators and Pathogens

Alternatives to traditional chemical insecticides such as predators, parasites, microbes and natural products have been gaining interest among researchers interested in developing integrated pest management approaches for insect control [122].

Despite the wide organisms range reported in its action as natural controllers of insect pests, weeds and diseases from the point of view of conventional biological control organisms used as biological control agents are classified into four categories: parasitoids, predators, pathogens and antagonists [12].

Parasitoids

Parasitoids also called parasites, are insects that perform most of their life cycle on a single prey, of which are nurtured and finally often kill shortly before becoming adults. Many parasites are host-specific, meaning they attack only one or at most a few closely related species of host [14]. Generally they are monophagous and develop on or within a single individual host from which they feed their body fluids, organs and ultimately cause her death [3].

Parasite are usually members of the order Hymenoptera (wasps, bee□s and ants), adults are free living like and lay their eggs on a specific prey and the immature stage lives on or inside a host before the host completes its development [11]. This process killing the insect pest, and giving birth to new parasitoid adults. Wasp parasitoids are more common than fly parasitoids. Parasitoids are very susceptible to pesticides because they feed on flower nectars which contain no natural poisons, and are normally exposed to pesticides because they are active searchers [114].

Approximately 15% of all insects are parasitic, ie, approximately 150,000 species are potential biological control agents [12]. Within the Diptera order these families Cecidomyiidae, Acroceridae, Nemestrinidae, Bombyliidae, Phoridae, Pipunculidae, Conopidae, Pyrgotidae, Sciomyzidae, Cryptochetidae, Calliphoridae, Sarcophagidae and Tachinidae, include parasitic species, but Tachinidae, Phoridae and Cryptochetidae are the most important [3]. Furthermore, at least 36 families of the Hymenoptera order have parasitic species, but the most outstanding parasitoids for biological control belong to two superfamilies, Chalcidoidea and Ichneumonoidea; Encyrtidae and Aphelinidae are the families most used in biological control of a total of 16 that belong to the superfamily Chalcidoidea [3].

Ichneumonoidea superfamily consists of two families, Ichneumonidae, members of this family parasitize different types of hosts, different species have antennae and long ovipositors other are short and not visible; species of the Braconidae family are widely used in biological control, especially against aphids, larvae of different species of the order Lepidoptera and Coleoptera, in this family there are different types of endoparasitoids, as in the case of endoparasitoids adult beetles and nymphs Hemiptera and endoparasitoids egg-larval Lepidoptera. From Chrysidoidea superfamily, the Bethylidae family are the most important for biological control, although several species are released Dryinidae pests of crops and ornamental [123].

Parasites can be classified into two groups according to where are situated to feed. Ectoparasites feed externally of their hosts and endoparasites feed internally of their hosts. Parasitoids usually placed one or more eggs outside the host body or they insert the eggs into its host. The immature state of the host parasitoid feeds and requires an individual prey to complete its development until it becomes an adult [14]. On the other hand, adults are free-living and can feed on nectar from flowering plants obtain nutrients or piercing the body of the insect host and extract fluids (host-feeding). Parasitoids attack a particular stage of the host but all host stages are attacked by several parasitoids. Parasitoids are generally small, easily overlooked and can be difficult to distinguish from other small flies and parasitic wasps do not. Also, a big advantage is that the parasitoids are not harmful to humans and tend to attack and parasitize one, or at most a few species, closely related insect pests [11].

Parasites are often considered more effective natural enemies than predators because many have a narrower host range, require only one host to complete development, have an excellent ability to locate and kill their host and can respond rapidly to increases in host populations [11].

Furthermore, the use of insect parasitoids to control pest species in bulk grain storages and in food processing facilities and warehouses have been proved to be effective in suppressing a limited number of pest species [124]. *Theocolax elegans* is an effective parasitoids, that is a small pteromalid wasp (1–2 mm), that attacks primary grain pests, whose immature stages develop inside the grain kernels, including the weevils, *Sitophilu*s spp., lesser grain borer, *Rhyzopertha dominica* (F.), drugstore beetle, *Stegobium paniceum* (L.), cowpea weevil, *Callosobruchus* spp., and Angoumois grain moth, *Sitotroga cerealella* [125-27]. However, this small pteromalid wasp does not parasitize species that are secondary grain pests, like the flour beetles, *Tribolium* spp., and the rusty grain beetle, *Cryptolestes ferrugineus* (Stephens), whose immature stages develop outside of the grain kernel [128].

Other species were biological control is extensively used is the sugarcane that growin in many regions of South America. In Brazil, the tachinid larval parasitoids, *Metagonistylum minense*, *Paratheresia claripalpis* and the braconid *Cotesia flavipes* have been routinely released for the control of *Diatraea saccharalis* [129]. Since 1988, parasitoid releases have reduced the infestation intensity to an average of 10% and in 1994 to about 3% [130]. Similarly in Venezuela, *Diatraea* spp. occurring there were no longer considered of consequence because of good biological control. This has been possible due to the effective larval liberation of the parasitoid *M. minense* [129]. Later, *Conops flavipes* was released providing more effective control. Because it was observed that 16% infestation was recorded in 1947 and in 1996 this infection was only 2% [131]. For its part, in Colombia using artificially reared larval parasitoids of *M. minense* and *P. claripalpis* have obtained effective results against *D. saccharalis* and *Diatraea indigenella*. Also, parasitoid eggs have been released [129]. Other species including *Trichogramma pretiosum* and *Trichogramma exiguum* have been released; however, no field recoveries have been made of *T. pretiosum* [132]. Worldwide *Trichogramma* warps (Chalcidoidea) are the most commonly used parasitic insect in augmentation programs. In the United States, at least six species are available, mainly used to combat the eggs of various moth. Of which, *T. pretiosum* and *T. minutum* are best suited for use in field crops and row crops, where may attack the eggs of different pests including cabbage looper, diamondback moth, corn earworm, and European corn borrer [14].

In Mexico, biological control is one of several strategies adopted for the control of borer complex, which comprises three species of a *Diatraea* as well as *E. loftini* [129]. The indigenous parasitoid, *Allorhogas pyralophagus*, has limited impact, but releases of *M. minense* have had some influence on damage [133]. In North America, some attempts have focused on two species of *Cotesia*, viz: *C. flavipes* and *C. chilonis*. Although these parasitoids have not yet become established, levels of parasitism by *C. flavipes* and *C. chilonis* were as high as 15% and 55%, respectively [134].

Like *Trichogramma*, adult *Encarsia* warp is tiny, less than one mm in size. *Encarsia* can be used successfully against greenhouse whitefly, species, such as sweetpotato whitefly, *Bemesia tabaci*. For example, *Encarsia formosa* is a parasite of greenhouse whitefly, *Trialeurodes vaporariorum* [14].

E. formosa feeds on the fluids that are excreted from the wound that it causes on the host by its ovipositor. This host feeding behavior occurs in all stages of the whitefly [135]. Methods used for the introduction of *E. formosa* into the greenhouse are the pest-in-first method and periodic introductions. The pest-in-first method is applied by introducing a low number whitefly on certain plants, followed by the introduction of the wasp [136].

Moreover, greenhouse whitefly occurs in all stages simultaneously (eggs, nymphs, and adults). For that reason it is therefore best to make serial releases of the parasite, which attacks only the nymphal stages [14].

Many larval stages of beetles are important pests of trees to which they cause serious damage. For example, *Atanycolus hicoriae* is a small parasitic wasp of Emerald ash borer (*Agrilus planipennis*). It is a solitary ectoparasitoid; its larvae develop singly while feeding externally on the *A. planipennis* host. Moreover, adults attack emerald ash borer larvae by inserting its long ovipositor through the bark of a tree and laying an egg on a larva. Then the wasp larva emerges and start to feed externally on the *A. planipennis* larva, eventually forming a cocoon from which and adult will later emerge by chewing through the bark [137].

Predators

The predator is a free-living organism throughout its entire life cycle, usually larger than their prey, requires more than a single prey to complete its development and always kills its prey [11,138]. For this purpose they may use camouflage to blend into its surroundings and wait for prey or may be active hunters [11].

Many kinds of predators feed on insects and for that reason insects are important food recourse for many vertebrates like fish, amphibians, reptiles, birds, and mammals. Predators are often large, active, and/or conspicuous in their behavior, and they are therefore more readily recognized than are parasitoids and pathogens [14].

Familiar predators of insects refers to those organisms that eat insects directly and include fish, amphibians, reptiles, birds, small mammals and arthropods [11]. Among all of these predators, arthropods (insects, mites and spiders) are the most important in pest management and include lady beetles, ground beetles, syrphid flies, green lacewings, assassin bugs, predaceous bugs, minute pirate bugs, predatory mites, and spiders [14].

In general predatory insects often feed on eggs of other insects, larvae, pupae or even adult. This type of insects can be divided into two groups: a) chewing; they eat and devour their prey and sucking: absorbing and suck the juices of their prey by means of a stylus or similar structure. Predators simply eat other insects during one or more life stages of their life cycle, some examples are, a ladybug or lady beetle eats aphids, caterpillar eggs, and small caterpillar larvae in its adult and larval stage. Normally, predators are not as specific as parasitoids in their host range, and may feed on a number of different insects [114].

Predators usually deposit their eggs near their prey so the immatures specimens can immediately find their host and begin feeding. Immature stages of predators are mobile, usually consume more than one prey during their development, are often generalist feeders (more than one species of host is attacked), and usually both the adults and immatures feed on the prey insect [11].

The use of predators in agricultural systems is becoming greater, but the success of this alternative pest management is linked to knowledge of the taxonomy and biology of predator specificity and predation rates [139].

The taxonomic orders of potential use in biological control are: Dermaptera, Mantodea, Hemiptera, Thysanoptera, Coleoptera, Neuroptera, Hymenoptera and Diptera, but Hemiptera, Coleoptera, Hymenoptera and Diptera are the most important. On the other hand, at the family level, there are more than 30 families of predatory insects, of which Anthocoridae, Nabidae, Reduviidae, Geocoridae, Carabidae, Coccinellidae, Nitidulidae, Staphylinidae, Chrysopidae, Formicidae, Cecidomyiidae and Syrphidae are the most important in the pest management in agroecosystems [123] and eight families of the subclass Acari represent great potential for biological control, among these are: Phytoseiidae, Stigmaeidae, Anystidae, Bdellidae, Cheyletidae, Hemisarcoptidae, Laelapidae and Macrochelidae [139].

Bugs

Many of the true bugs are predatory insects, they are predaceous as nymphs and adults, are very active hunters and their prey range from insect eggs, young caterpillars, aphids and spider mites to other plant bugs. Common members of this group are the minute pirate bug (*Orius tristicolor*) and flower bug (*O. insidiosus*) which are abundant throughout North America [11].

Insects

Many adult and larval stages of beetles are predators that may feed on all types of insects, arthropods slugs and snails. They may be found living in the soil, on the soil surface, or on plants. Their prey may be varied or specific. For example, lady beetles include numerous species that are common predators of aphids and other small insects and insect eggs, are readily recognized [11].

Other insects such as dragonfly larvae and aquatic beetles may feed on mosquito larvae, but are not very effective in controlling their density [140].

Coleoptera order includes over 110 families, many of which are predators. Among them, the most important families used for biological control include: Coccinellidae, Carabidae and Staphylinidae [12].

Coccinellidae

Coccinellidae is the most important group of predators used for biological control of both native and exotic pests. They are commonly known as ladybirds, ladybugs, lady cows, ladybird beetles or lady beetles. Most species of ladybugs (adults and larvae) are beneficial, although there are two exceptions: *Epilachna varivestis* and *E. borealis*; which, both larvae and adults, of both species feed on plants [12].

The lady beetle species that is most commonly available is the convergent lady beetle, *Hippodamia convergens*, both larvae and adults are active predators, that prefer to feed on aphids, but they may also feed on other small, slow-moving, soft-bodies insects and mites. Ladybugs commonly are red, orange or yellow with black spots. Others are black with red spots. Adults are about 5 mm long, with oval body and elytra orange or red with black or brown spots. Adults are small, oval and domed [12].

Members of the Coccinellidae group lay their eggs in clusters on leaves, which are yellow to orange, with elongated shape. When the larvae hatch from eggs are dark colored, lizard-shaped, with three pairs of prominent legs. Depending on the species and the availability of prey, the larvae grow less than 1.0 mm to more than 1 cm long, typically through four larval stages, over a period of twenty to thirty days. Larger larvae can travel up to twelve meters per day in search of prey, and in some species the larvae are gray or black with yellow or orange spots or stripes. The last larval stage remains relatively inactive before clamped by the abdomen to a leaf or other surface to pupate. The pupa is dark or yellow-orange. The pupal stage lasts three to twelve days, depending on species and temperature and the adults live from a few months to over a year. Common species produce one or two generations per year [12].

Among the introduced species of ladybirds that have controlled important pests include: *Rodolia cardinalis* which controlled the cottony cushion scale, *Icerya purchasi* (Homoptera: Margarodidae) in California [141].

On the other hand, *Cryptognatha nodiceps*, *Chilocorus distigma* and *Chilocorus nigritus* have been used to control the flake coconut *Aspidiotus destructor* (Homoptera: Diaspididae) in the Seychelles archipelago in the Indian Ocean [52].

Other species, the mealybug destroyer, *Cryptolaemus montrouzieri*, is much smaller than the convergent lady beetle and is more specialized, it feeds mainly on insects. These beetles have a good control of mealybugs in commercial and hobby greenhouses, especially in hot and humid conditions, where the numbers of mealybugs are high [14].

Delphastus species, like *Delphastus pusillus* and *D. catalinae* are more effective natural enemies at high whitefly populations. However, both adults and larvae avoid eating whitefly nymphs that contain later stages of parasitoid wasps [14].

Many crops benefiting from the presence of ladybirds, especially any crop attacked by aphids. Therefore, ladybirds are considered one of the most beneficial natural enemies worldwide [12].

Some of this ladybirds, are collected in large numbers of large hibernating clusters in the hills and mountains [14]. On the other hand, other species of ladybirds are commercially bred and released massively to control whiteflies, mites, scales, aphids in greenhouses, or inoculation seasonal outdoor crops [142]. Inundative releases of field collected convergent lady beetles, can thus help control large populations of aphids, being more effective when they are use in large areas than in small areas [14]. Coccinellidae augmentation examples include *Stethorus punctillum* (for controlling mites) *Chilocorus nigritus* (flake control) and *Cryptolaemus montrouzieri* (*Pseudococcidae* control) [142]. *Stethorus punctillum* is a specialist mite predator, especially of European red mites on fruit trees. This predator has been used in greenhouse conditions to control mite pest in cucumber and pepper crops [14].

Among the main species of Coccinellidae predators: *Coleomegilla maculata,* inhabits in crops that have been attacked by aphids or other reported prey. The most important crops where they inhabits are: wheat, sorghum, alfalfa, soybeans, cotton, potatoes, corn, peas, beans, cabbage, tomato, asparagus and apple. Both adults and larvae of *C. maculata* are important predators of aphids but also feed on mites, insect eggs and small larvae. They also consume pollen, which can constitute 50% of their diet. Meanwhile, *Coccinella septempunctata,* was repeatedly introduced from Europe to North America for biological control of aphids. *C. septempunctata* is more effective than native ladybirds predator species and reaching displace them in some areas. *C. septempunctata* can be found in all crops that are infested by aphids, including: potatoes, beans, corn, alfalfa, wheat and sorghum. This predator attacks the following aphid species: *Myzus persicae*, *Macrosiphum rosae*, *Aphis gossypii*, *Acyrthosiphon porosum*, *Rhopalosiphum maidis* [12].

Chilocorus kuwanae, has been imported from Korea as part of biological control program of euonymous scale *Unaspis euonymi* (Homoptera: Diaspididae) in the United States. Generally found in vegetation attacked by euonymous scale *U. euonymi* and other species of scales. For its part, *Cryptolaemus montrouzieri,* lives in the citrus groves in California. In which was introduced from Australia, in 1891 by Albert Koebele, to control the citrus mealybug. *C. montrouzieri* attacks the citrus mealybug and related species, and recently has been used to control the mealybug *Maconelicoccus hirsutus* [12].

Other important specie, *Hippodamia convergens,* is found from Southern Canada to South America. In insectaries sell them for aphid control. Both adults and larvae feed primarily on aphids (*Myzus persicae*, *Macrosiphum rosae*, *Aphis gossypii*, *Acyrthosiphon porosum*, *Rhopalosiphum maidis*). If aphids scarce, they also feed on larvae of other insect species, eggs, mites and occasionally nectar and honeydew produced by aphids [12].

Finally, *Rodolia cardinalis,* was introduced in 1888 in the California fields from Australia to combat the cottony cushion scale of citrus *Icerya purchasi.* This scale caused severe infestations in citrus orchards of California, to the point that the producers had to knock down and burn the trees. *R. cardinalis* introduction is considered the start of classical control [12]. From the population of 514 individuals introduced in 1888 in California, were produced descendants who have served for releases in France, Italy, Portugal, Russia, Peru, Argentina, Uruguay, Chile, Puerto Rico, Venezuela, Hawaii, the Philippines, Egypt, Cyprus, Guam and Taiwan [12].

Carabidae

Most members of this group are generalist predators that live on or near the ground, where they feed mainly at night. Carabids are small, 8-25 mm long, with a dark or metallic coloration [12]. Carabids feed on aphids, spiders, larvae and adults lepidopteran, Diptera larvae, mites, hymenopterans, homopterans, beetles, collembolans and opiliones [143].

Many species are important forage predators and cereal crops in strips [144]. Some investigated agricultural practices to conserve carabids include: application of pesticides only in specific areas (stripes), conservation of certain weeds in the fields, cover crops, mulch and manure application [145]. At some occasions carabids have been introduced to new regions with some specific habits to control exotic pests, such *Calosoma sycophanta* that was introduced to North America for control of *Lymantria dispar* [12].

Among the main species of carabids, *Lebia grandis* inhabits in all crops attacked by the potato beetle *Leptinotarsa decemlineata*, and the beetles of the Dysticidae and Gyrinidae families, which are important predators of agricultural pests in aquatic systems like rice, or for pest control in wet areas [146].

Staphylinidae

Most beetles of the Staphylinidae family are predators, and are found where there plenty of organic matter [12]. On the other hand, some species are important predators of eggs and larvae of flies that attack the young roots of onion, cabbage and broccoli [147].

Among the main species, can mention *Aleochara bilineata*, whose adults are predators and its larvae parasitoids. Mainly, is found on crops of onion, cabbageradish maize and others; generally consume eggs, larvae and pupae of the onion rootworms *Delia antiqua*, and cabbage *Delia radicum* (Diptera: Anthomyiidae). Predation may be 90 to 95%, although the adults emerge too late, ie, several weeks after the *Delia* adults have emerged; therefore, can be given damage to crops [12].

Some species of the Histeridae family prey on pests that feed on dung, as *Musca domestica*. In North Carolina *Carcinops pumulio* was reported as an important predator of eggs and larvae of *M. domestica* in poultry systems. On the other hand, the larvae of some species of the family Cantharidae prey on aphids and other prey, such as locustos eggs [12]. Many members of the Cleridae family are predators both larvae and adults beetles from the Scolytidae family in Central Europe [148]. Finally, some species of the Cybocephalidae family are predators of scales and whiteflies [149].

Neuroptera

Some families of this order are predators in aquatic habitats, such Sialidae and Corydaliae, but the types of organisms that consume have not been of great interest for biological control. The main families of Neuroptera used in biological control are: Chrysopidae, and Coniopterygidae Hemerobidae [12].

Lacewing adults are fragile-looking insects that laying their eggs individually on top of a slender stalk attached to a plant. The elongate, flat, mottled brown larvae move quickly over the plant in search of prey. They have large, sickle-shaped mandibles that they use to capture and hold prey as they suck out the body fluids [11]. Although the adults in the Chrysopidae family feed only on nectar, pollen and aphids honeydew, their larvae are active predators. Others like *Chrysoperla carnea* are predators of aphids, whiteflies and eggs of several species including *Helicoverpa* [12,14]. Lacewings generally released as eggs or larvae and are often an effective strategy for the control of aphids in greenhouses [150] and potentially for some crops with pests like *Aphis pomi* [151], *Helicoverpa zea* and *Helicoverpa virescens* [152].

Green lacewings are somewhat specialized for feeding on aphids, but they will also feed on an assortment of other small insects and mites. The larvae, called the aphidlion, [14] feed on many soft bodied insects, chiefly aphids, as well as small caterpillars, insect eggs, and mites. They are most abundant later in the season [11]. The larval stage, is the most important stage for pest control [14].

Moreover, members of the Hemerobidae family, are less common than green lacewings and can be found in shrubland. Lastly, members of the Coniopterygidae family feeding mites, eggs and other small prey [12].

Hemiptera

This order contains many families whose members have predatory habits. Like the hemiptera of the Anthocoridae family that are important predators of phytophagous thrips and eggs of pests such as *Ostrinia nubilalis* [153]. *Orius tristicolor* has grown in laboratory for use against aphids [154].

Among the main Anthocorids is located *Orius* spp. that inhabits, usually in cotton, peanuts, alfalfa, corn, peas, strawberry and pastures where both adults and nymphs feed on prey including thrips, mites, aphids and other insect eggs and small Lepidoptera larvae [12]. Minute pirate bugs, like *Orius* species, are tiny predatory bugs that feed on mites, small insects such as aphids and thrips, and insect eggs. However, although these predators are useful in outdoor and greenhouse conditions, may occasionally bite humans and their bite can be detected due to temporary irritation [14].

Although, many members of the Lygaeidae family are herbivores, like bugs, *Oncopeltus fasciatus* and *Blissus leucopterus*, some genera are predators like *Geocoris* that feed of insects on grasses and many cotton pests [155]. Are the most important predator insects and abundant in several crops, among the most common species are *G. punctipes, G. pallens, G. bullatus* and *G. uliginosus* [12].

On the other hand, the Pentatomidae family contains many important herbivores as pest species, however, some species such as *Podisus maculiventris* and *Perillus bioculatus* are important predators of considerable pests such as *Leptinotarsa decemlineata* [12]. Another family that contains many herbivorous species, such as *Lygus lineolaris* is Miridae; however, some groups are predators, is the case of *Deraeocoris* spp., which feeds on aphids and other small insects [52].

Other important hemipterans are nabids that feed on insect eggs, aphids and other slow insects, small in size and soft body. *Nabis ferus* is well known as a predator of the potato psyllid, *Paratrioza cockerelli* and the beet leafhopper, *Circulifer tenellus* [12].

Several families of hemipterans predators live in aquatic environments: Notonectidae, Pleidae, Naucoridae, Belostomatidae, Nepidae, Gerridae, Veliidae, among others. This group may be important in suppressing plagues of aquatic systems, such as rice, also suppresses some medically important pests such as mosquitoes and snails [156].

The spined soldier bug, *Podisus maculiventris*, kills its prey by sucking out its body fluids. In Mexico, this beetle predator, have been used for control the Mexican bean beetle and Colorado potato beetle, as well as various caterpillar pests [14].

Diptera

The Diptera families in which biological control has been more significant are: Cecidomyidae, Syrphidae and Chamaemyiidae, which include species that attack aphids and other important herbivorous pests. Some species of these groups have been of great value in the classical biological control of exotic pests [12].

Many species of the Cecidomyidae family form galls; however, some species are predators of aphids, scales, whiteflies, thrips and mites [12]. The species most known is *Aphidoletes aphidimyza*, which grows and sells for aphid control in greenhouses [14, 157]. On the other hand, adults of many species of the Syrphidae family are important predators of some aphid species [158]. Although many species of syrphid look like bees, they do not bite [12]. Finally the larval stage of many species of the Chamaemyiidae family are predators of aphids, scales and Pseudococcidae, also are important controllers of certain natural pest aphids [159]. Some species have been introduced into new regions to control exotic pests, such as *Leucopis oscura* which was introduced in Canada to control pine aphid *Pineus laveis* [52].

Hymenoptera

The major predators groups in this order include the ants family Formicidae and the wasps families Vespidae and Sphecidae [12]. The Fornicidae family contains many species with herbivorous habits, predators and decomposers [160]. Predatory ants are a tremendous resource of nonspecific predation since they have demonstrated efficacy in suppressing pests and forest crops [161]. Being the conservation of native ant species an important resource for natural pest control [162].

For their part, most members of the Vespidae family are social species whose adult capture various insects, including many Lepidoptera larvae as food for their larvae [12]. These insects have great value in the removal of some insect pests such as the cassava hornworm *Erinnyis ello* [163]. However, since its action is not directed to a particular pest species, have the potential to threaten certain species that are not pests. Another disadvantage of this group as biological control agents is represented by its management because they strongly bite people. By contrast, the Sphecidae family are not social habits wasps and feed of a wide range of arthropods which includes several lepidopteran and spiders as food for larvae [12].

Other predators

Although the vast majority of the species of the Lepidoptera order are herbivores or decomposers, in some families as Lycaenidae, Blastobasidae, Heliodinidae, Psychidae, Olethreutidae, Pyralidae, Noctuidae and Arctiidae exist some species with predatory habits. Typical prey are scales, aphids and other insects of slow moving or sessile. For example, *Amata pascus* is used in China as predator in an augmentation via of the bamboo diaspidid scale *Kuwanaspis pseudoleucaspis* [164].

There have been some efforts to use lepidopteran predators as control agents introduced, but this order has been minor compared to Coleoptera, Diptera and Hymenoptera [12].

Many orthopterans are herbivores, mostly crickets and locusts, or decomposers like cockroaches [165]. The only family with consistent predatory habits is Mantidae. This family is mainly tropical, but some species have been introduced to new areas, for example, the Chinese mantis *Tenodera aridifolia sinensis* and the European mantis, *Mantis religiosa* were also introduced to the United States. Although these predators are bred and sold in commercial insectaries not provide effective control after their release [12].

Mantids are generalist predators that make no distinction between pests or beneficial insects. Their numbers usually decline rapidly after hatching, and they generally provide little if any significant value in pest control. Therefore, its use for biological control is not recommended for commercial agriculture, and its value in home garden is also questionable [14].

On the other hand, a few Orthopteran species from other families are also predators, such *Conocephalus saltator*, which feeds on aphids and scales. However, in general, the value of the orthopterans as biological control agents is limited [12].

For its part, Dermaptera it is easily recognized by its flow rates pliers. Most are decomposers, but a few species are predators of aphids and other small insects [12]. Cans filled with dry grass tied to trees are used to successfully increase the populations of these predatory earwigs of aphids on systems of fruit trees [166].

Most of the thrips (Thysanoptera) are phytophagous, and some species are major pests in crop plants. However, two families contain predatory species: Aleolothripidae with the species *Aleolothrips fasciatus*, which feeds on thrips, aphids and mites, and the Phlaeothripidae family, with the specie *Leptothrips mali* that feeds on mites, and *Aleurodothrips fasciapennis*, of white flies [12]. However, the biological importance of this group is not yet observed.

Arachnids Predators of Arthropods

Predatory spiders

Among the most ignored and least understood predators are the spiders, which have a strong stabilizing effect on prey. The spiders depend on a complex assemblage of prey. The result is a diverse community of spiders that maintains control over a prey population associated without reaching extinguishing it. In this way spiders function as regulators which limit the initial exponential growth of a specific population of dams [167].

All spiders are predaceous and generalist feeders, and their methods for capturing prey are varied, ranging from web spinning to active hunting [11,167,168]. However, because most of the spiders do not have prey specificity, but if specificity for their habitats. Some are used for the introduction in new regions in order to control specific pests. Instead, they are used in agricultural systems which use practices that preserve the native spider for removing some groups of insect pests in crops [12]. Among the most important families of spiders that are used as predators are found: Agelenidae, Araneidae, Lycosidae, Thomisidae and Salticidae [169].

Predatory mites

Of the twenty or more families of the order Acari that prey or parasitize other invertebrates, eight have a high potential for biological control, among these are Phytoseiidae, Stigmaeidae, Anystidae, Bdellidae, Cheyletidae, Hemisarcoptidae, Laelapidae and Macrochelidae [12,170].

Of these, the most important predatory mites are members of the family Phytoseiidae (also called phytoseiid mites) of which several species are used to control pest mites. Predatory mites are tiny about 0.5 mm when fully grown. Primarily they are used for strawberries and greenhouse crops, but predatory mites can be used wherever spider mites are a problem. For example, *Phytoseiulus persimilis*, is a highly specialized mite predator that will starve in the absence of spider mites [14].

Predatory mites are among the most effective biological control agents commercially available. These mites are about the same size as the pest mites. They move quickly through the colonies of mites pest in search of prey. Their eggs are oval, in contrast to the pest mite eggs that are spherical. These mites inhabit almost all crops attacked by pest mites and thrips [12].

Phytoseiid species have been introduced for the biological control extensively [99]. Being extensive his study on apple [171], on grapes (*Vitis vinifera*) [172], strawberries (*Fragaria xananassa*) [173] and other crops. Among the main species of predatory mites in this family are found:*Phytoseiulus persimilis*, *Galendromus occidentalis*, *Neoseiulus fallacis* and *Galendromus pyri* [12].

The species of the Stigmaeidae family are predators of the pest mites of the famillies Eryophydae, Tenuipalpidae and Tetranychidae. For example, *Zetzellia mali* is one of the most important species to control pest mites in apple orchards in some areas [174]. One of the species of the Anystidae family that is used with good result in biological control programs is *Asistis salicinas* [175]. On the other hand, some species of the Bdellide family are important predators of red spiders in grapes [176] and collembolans [177].

Of the Cheyletidae family is suggested the species *Cheyletus eruditus* to control stored product pests [12]. Other families like Hemisarcoptidae are predators of scales [178-180]. Inside the Laelapidae family the populations of *Androlaelaps* sp. and *Stratiolaelaps* sp. in corn plants, caused 63% mortality of eggs rootworm *Diabrotica* spp., in soils fertilized with animal manure [181]. Finally, within the Macrochelidae, family *Macrocheles* species are important predators of fly eggs in manure [182].

Vertebrate predators

Bats, birds, frogs and toads can be important agents in the natural control of insects, and their contribution to biological control can be enhanced through appropriate conservation practices [14]. Bats are responsible for capturing night flying insects such as moths, beetles, bugs, grasshoppers and mosquitoes. Their presence in a given area depends largely on the availability of adequate housing and access to water pools of at least 10 feet wide from which to drink while on the wing [14].

Birds can complement the activity of bats by feeding on insects during the day. Some birds feed primarily on insects during the nesting season, then switch to a diet consisting mostly of seeds. In field settings, bluebirds, barn swallows, wrens, sparrows, and starlings can consume many insects, at least sometimes. In orchards, titmice, chickadees, nuthatches and woodpeckers are important predators of insects in trees throughout the year, not just during the summer. Because the various insect-eating birds prefer different habitats and forage in different ways, conservation practices (housing, water, supplemental foods) must target the desired species in order to be effective [14].

Within ecosystems frogs are an important part because they control insects and pests. However, the use of frogs and tadpoles for disease vector control is still largely unexplored [183]. Frogs belong to the order Anura which comprises a total of 5362 species in 45 families [184]. Worldwide frogs are present on all continents except Antarctica and some Oceanic Islands. Its origins date back to 292 million years ago and they have adapted to a variety of ecological environments [185]. Toads and frogs consume large numbers of insects, slugs, worms and other invertebrates. Their presence in agricultural settings depends on a diversified habitat that provides shelter, adequate prey and pools of water for breeding sites [14].

Most of the species of tadpoles are omnivorous as they feed a lot of microorganisms like protozoa, algae, shrimp, insect larvae, eggs and young of other amphibians. As for adults, most species are carnivorous and typically consume invertebrates such as gastropods, annelids and arthropods. Moreover, some species can feed vertebrates such as fish, smaller frogs and small mammals [183]. Studies have shown that 50 frogs can keep an acre of a rice paddy field free of insects [186].

Of all the mosquitoes genera few are the main vectors of human diseases such as malaria, filariasis and viral diseases such as Japanese encephalitis, dengue, dengue hemorrhagic fever, yellow fever, chikungunya, etc. [187]. On this point, frogs introduced into segregated mosquito larval breeding habitats such as ponds, puddles or tanks, may prey on larvae and subsequently reduce vector population and vector borne disease burden [188]. On the other hand, selective removal of predators in the habitat due to the use of pesticides [189] or other means might possibly cause an increase in vector populations and therefore the disease burden [183].

Tadpoles are responsible for consuming mosquito larvae while frogs can reduce the mosquito population hunting adult mosquitoes. About that studies on predation efficacy of four Australian tadpoles was very low and was stated to be not an useful biological control agent [190]. However, many studies indicate that mosquitoes are not the only preferred prey for frogs [183].

Biological control for fishes includes the introduction of carnivorous fish species, like walleye (*Sander vitreus*), largemouth bass (*Micropterus salmoides*), species in the Salmonidae family, and the development of targeted disease agents as biological control agents against invasive fish [56].

Different introduced predatory fish species and specific pathogens agents have been considered for biological control of some species such as silver carp (*Hypophthalmichthys molitrix*) and bighead carp (*H. nobilis*). Other species such as Molluscivorous fish may be effective for the control of the greater European European pea clam (*Pisidium amnicum*), European fingernail clam (*Sphaerium corneum*), and the European stream valvata (*Valvata piscinalis*) [56].

Pathogens

Insect like other animals and plants, are subject to be attack by diseases caused by pathogens like fungi, viruses, bacteria, protoctists and other microorganisms [11,14]. Insect-parasitic nematodes are also included in this group of natural enemies. These diseases may reduce the rate of feeding and growth of insect pest, slow or prevent their reproduction, or kill them. All these entomopathogenic organisms may be potentially useful as biological control agents against a particular pest insect [191,192].

Both pathogens and nematodes, like parasites, tend to be specific to certain species or groups of pests; they do not harm no target organisms, such as beneficial insects, animals, humans, or plants. They can quickly spread through an insect population causing rapid mortality in a short period of time, and can be important in the natural control of pest populations [11].

Epidemic disease among insects are not commonly found in nature except when insect populations are large or when environmental conditions favor the growth of the organism responsible for causing the disease. However, pathogens that affect insects are important to the continued removal of pest populations [14]. In addition, a growing number of insect pathogens have been developed into commercial products for use in the biological control of specific pests of human interest [14]. The most familiar pathogens are discussed in detail in the next paragraph.

Bacteria

In recent years, various species of pathogenic bacteria have been isolated, and have been developed as pesticides and successfully used in the biological control of insects worldwide [192]. Most pathogenic bacteria are introduced to the hosts when they eat contaminated food. These bacteria multiply in the digestive tract of insects, producing some enzymes (such as lecithinase and proteinase) and toxins which damage the midgut cells and facilitate the invasion of the insect haemocoel [2].

Bacterial pathogens used for insect control are spore forming, rod-shaped bacteria in the genus *Bacillus* [193]. The genus *Bacillus* is the most important in insect pest management. Its different strains are commonly used for control of many insects, including various caterpillars, mosquito larvae and Colorado potato beetle larvae [14]. Species in this genus form spores that are toxic to the insect when ingested. Symptoms of infected insects include a loss of appetite, sluggishness, discharge from the mouth and anus, discoloration and liquefaction and putrefaction of the body tissues. For example, *Bacillus thuringiensis* (commonly called Bt) is the most widely-used bacterium for insect pest control [1,14]. *B. thuringiensis* is a ubiquitous, spore-forming, rod-shaped, Gram-positive bacterium that produces massive amounts of one or more proteins that crystallize intracellularly during sporulation stage [1]. Different strains of *B. thuringiensis* are specific against caterpillars, mosquito larvae and some beetles and their larvae. *Bacillus popillae* and *B. lentimorbus* cause "milky disease" of white grubs. "Milky disease" refers to the white discoloration of the insect blood [11].

The steps that follow infection varies with the type of bacteria. Usually, once invading the hemocoel, they multiply and kill the host by septicemia, by the action of toxins or both. In many cases, before dying, the host insect loses appetite and stops feeding. At other times infected hosts may defecate or vomit, distributing with the entomopathogenic this organism. Insects die from a bacterial infection, usually become dark and his body becomes limp. Tissues can be viscous and have rotten smell [2]. Some bacteria infect the progeny of insects either in eggs or in such as the case of *Serratia marcescens* Bizio in brown lobster *Locustana pardalina* [123].

Proteins (*Cry* proteins) produced by *B. thuringiensis* are toxic mainly to insect larvae in order Lepidoptera, Diptera, and Coleoptera, but isolates with toxicity toward Hymenoptera, Homoptera, Orthoptera and Mallophaga and against nematode, mites, lice and protozoa have been discovered too [194].

Viruses

The larvae of many insect species are vulnerable to devastating epidemics of viral diseases. Viruses that cause these outbreaks are very specific, usually acting against only a single genus or even a single species [193].

Entomopathogenic viruses have been employed in biological control of insect for a wide range of situations from forest and field to food stores and greenhouses [1]. Insect viral pathogens vary in the way they attack and kill its host. Most insect viruses, like bacteria, have to be ingested in order to successfully infect its host; however, some can be transferred by insect parent to offspring through eggs [193]. Generally, the infected insect die one or two days after symptoms appear; later, the cadaver will burst, releasing the viral particles into the environment. Some of the important groups of viruses that attack insects are the Nuclear Polyhedrosis Viruses (NPVs), Cytoplasmic Polyhedrosis Viruses (CPV) and Granulosis Viruses (GV) [11,193].

The *Baculoviridae* family is the largest and most studied of entomopathogenic virus. This family groups together double-stranded DNA viruses whose virions are typically included in a protein matrix called polyhedron or inclusion body [195]. Baculoviruses as microbial insecticides are ideal tool in integrated pest management, as they are highly specific to their host insects, therefore it is safe for the environment, humans, plants, and natural enemies [196, 197]. More than 50 baculovirus products have been used to control different insect pests worldwide. The use of the nucleopolyhedrovirus of *Anticarsia gemmatalis* NPV to control *A. gemmatalis* in soy in Brazil was a successful program and was considered the most important in the world [197,198].

The introduction of the NPVs in populations of *Neodiprion sertifer* in forests pine in Canada, is another example of the adaptation of this entomopathogen in an ecological determined medium [89]. The inoculum was introduced in Switzerland in 1949 and was propagated in larvae of the population; was established a permanent epidemic, up to fully control the pest [199].

NPVs are formulated to be applied as spray in a similar way as chemical insecticide and *B. thuringiensis* strains are apply. However, its effect has been moderate due to several key limitations, which include a relatively slow rate of deaths, a narrow spectrum of activity, lower persistence in the field, and lack of a cost-effective system for mass production *in vitro*. Fermentation technology for their mass production on a large-scale commercial basis is extensively investigated to reduce the production cost [1].

Most viruses that have been developed for use as insecticides, are specific to a single species or a small group of forest related forest pests, for example, the gypsy moth, Douglas-fir tussock moth, spruce budworm and pine fly sawfly. Other insect viruses investigated for use as insecticides include those that infect the alfalfa looper, soybean looper, armyworms, cabbage looper, and imported cabbageworm. However, although some of these viruses have been formulated and applied in field tests, none has been registered or sold commercially [193].

Fungi

Fungi, like viruses, often act as important natural control agents that limit insect populations. Most of the species that cause insect diseases spread by means of asexual spores called conidia [193].

Knowledge of the effect of environmental factors such as temperature, humidity and radiation on the survival of microorganisms in the host are essential to recommend the use of entomopathogens in pest control; release shall be made at the time in which these factors are favorable [89]. On the other hand, there are many ways in which entomopathogenic organisms can operate [200]. Insect pathogenic fungi produce spores that germinate once they come in contact with the insect cuticle, when conditions of temperature and humidity are favorable. Once in the insect cavity, hyphae rapidly grow, filling the body cavity with a fungal mass, which kills the insect. Furthermore, the fungus also may produce one or more toxins. Once the insect is dead, the hyphae penetrate outwardly through the softer insect and favorable moisture conditions mature and produce spores that are released into the environment to complete the life cycle [11].

Although over 750 species of entomopathogenic fungi were reported to infect insects, few of them have received serious consideration as potential commercial candidates [1]. The first registered mycoinsecticide was made by *Hirsutella thompsonii*, which has been known to cause dramatic epizootics in spider mites. Another fungus *Verticillium lecanii* and *Paecilomyces fumosoroseus*, have been registered for control of whitefly, thrips, aphids and spider mites [1].

There are many genera of fungi that attack insects and the most important ones are *Metarhizium, Beauveria, Entomophthora* and *Zoopthora*. For example, *M. anisopliae* and *Beauveria bassiana* attack a wide range of insects, such as grasshoppers, true bugs, aphids, caterpillars, and beetles [11]. The broad host range of some insect fungi like *M. anisopliar* and *B. bassiana* is an attractive characteristic for insect pests control [1,89]. Therefore, *M. anisopliae* is especially recommended for practical control of termites as a bioinsecticide because it: (a) will not infect humans or higher animals; (b) is virulent to all species of termites tested; (c) has robust conidia that are easy to formulate and store; and (d) has conidia that can survive >18 months in termite nests [81].

Virulence and repellency are two factors that must be addressed to improve the efficacy of *M. anisopliae* [78]. Furthermore, the repellency of conidia of certain fungus strains of highly virulent can be a problem to induce a continuous infection [201], to overcome this obstacle, it is necessary to use a non-repellent fungal conidial formula in order to kill termite colonies [78].

Other fungi as *Entomophthora muscae* attacks many types of adult flies including the seed corn maggot and the hover fly, a beneficial; on the other hand, *Zoophthora radicans* attacks the potato leafhopper and many aphids, and *Z. phytonomi* infects the alfalfa weevil [11].

The fungus *Nomuraea rileyi* (Farlow) Samson has used in California to induce early epizootics in populations of *Anticarsia gemmatalis* Hübner in soybean plantations [201-203]. The application of conidia pathogen suspended in water was obtained in laboratory conditions on Sabouraud maltose agar medium plus yeast extract at a concentration of 2.47 x 10^{13} conidia/ha gave 70% control after 5-10 days applied; this percentage is reduced due to the decrease of the plague and then progressively increases relative with the increase in the insect population to achieve 100% control after one month of the application [89].

Protozoa

Protozoa pathogens insect are single celled organisms that can grow and reproduce only within a cell of a host insect. Although some insect pathogens protozoa quickly kill their hosts, others produce chronic infections [193]. The infections caused by this type of protozoa often shortens the life of the insect and can reduce reproduction. This means that these protoctists often exert a constant, low level of suppression of insect populations instead of the sudden collapse of the population in a rapid epidemic [14].

Within the protozoa kingdom exist many insect pathogens, but the largest group is represented by the spore-forming microsporidia. Within this group, the genus *Nosema* has several species that attack at least 10 orders of insects, especially Lepidoptera (caterpillars), Coleoptera (beetles), Orthoptera (grasshoppers, crickets, and their relatives), and Hymenoptera (sawflies, bees, wasps and ants) [14,193]. The death rate in the genus *Nosema* infections is relatively low, but the effect on the reproduction reduces the host population in subsequent generations. Another *Nosema* specie, *N. pyraustae* is occasionally important in the natural control of European corn borer [14]. For locust control a formulated bait is used and produced commercially with the microsporidian protozoan *Nosema locustae* [165]. Because its action is relatively slow, usually is applied after the nymphs have emerged. Adults who survive the attack of this pathogen consume less vegetation and produce fewer eggs [204].

Species of the genus *Vairimorpha* mainly attack caterpillars, for example, *Vairimorpha necatrix* is more virulent than *N. lacustae*, resulting in a higher mortality rate. Furthermore, *Lagenidium giganteum* has been produced commercially for control of mosquito larvae of the genera *Aedes* and *Culex* [14].

One important and common consequence of protozoan infection is a reduction in the number of offspring produced by infected insects [193]. However, due to its relatively low virulence, and the relatively long period of infection before death, most protozoa are more important in the natural control than in biological control where their contributions will remain limited [14,193].

Nematodes

To be accurate, nematodes are not microbial agents but because of its microscopic size they are used much like the truly microbial products discussed previously. Nematodes used for insect control infect only insects or related arthropods so they are called entomogenous nematodes [193].

Approximately 20 nematode families have insect-parasitic species [14]. Nematode parasites of insect have enormous potential for biological control because of its wide range of insect pests. In terms of commercially important microbial insecticide they are probably second only to bacteria [1]. They are also called entomopathogenic nematodes because of their habits. Nematodes are small, almost microscopic worms that attack and kill insects that live in moist habitats, specially water and damp soil [14]. Producers who are interested in using biological control to combat insect pest populations on their plantations, are advised to start with beneficial nematodes; for example, to control Fungus gnats or fly mulch (*Scaridae*). The beneficial nematodes are relatively simple to use and are applied similarly to the conventional pesticides [205].

Nematodes are a phylum of pseudocoelomate worms with over 25,000 registered species, transparent and cylindrical species that are commonly found in soils worldwide [206]. Depending on the pest species, nematodes effectiveness for biological control may vary, working best with one or more different pests. For example, *Steinernema feltiae* is mainly used against fly mulch larvae and most recently against thrips pupae in the soil [205]. Nematodes have been traditionally used against soil pests because they are sensitive to ultraviolet light and dryness.

Commercially available species of nematode as bioinsecticide are in three families: Rhabditidae, Steinernematidae and Heterorhabditidae. Nematodes parasitize their hosts by direct penetration either through the cuticle or natural opening in the host integument [1], enter through the openings in their body, multiplying inside and release a symbiotic bacterium whose toxin kills the fly mulch. Larvae die in one or two days by blood poisoning. It is possible that more than one generation of nematodes developed in these insect host, and dead on the floor. Juveniles, infectious nematodes leave the body in search of new hosts that infect [205]. The symbionts are specific with members of the genus *Xenorhabdus* associated with the steinernematids and *Photorhabdus* associated with the heterorhabditids [194].

Nematodes can attack species within most orders of insects. The most common hosts are from the orders Coleoptera (beetles), Diptera (files, mosquitoes, and their relatives), Orthoptera (grashoppers, crickets, and their relatives), Lepidoptera (butterflies and moths), and Hymenoptera (sawflies, bees, wasps, and their relatives) [14].

The most common nematodes that parasitize grasshoppers belong to the Mermithidae family and includes the genera *Mermis*, *Amphimermis*, *Hexamermis*, *Agamermis* and *Longimermis* [207]. Its potential to be applied as biological control agents of inoculative mode for long-term control is great [207,208].

In late 1990 in the United Kingdom, was reported for growing chrysanthemum (cut flower) the weekly applied of foliar sprays of nematodes, being observed a reduction in populations of thrips (Thysanoptera) [205]. These insects cause damage in plants by feeding on the flowers or fruits of the host plant; in addition, they can act as vectors of more than 20 viruses, among which *Tospovirus*, including some of the most damaging viruses, such as tomato spotted wilt virus [209]. Even more recent studies in Canada, the United Kingdom and Germany have demonstrated that thrips stages of metamorphosis (especially the pupal stage) which are present in the soil, are very susceptible to several species of nematodes, including *S. feltiae* [205].

Insects in the Biological Control of Weeds

Biological control is the use of natural enemies (biological control agents) to control a target weed. Normally, females of outbreaks insect tend to lay their eggs in groups as opposed to species that disperse their eggs along the host plant. Some extreme cases are seen when females cannot fly and therefore deposit all their eggs in a single mass. The larvae that emerge from these outbreak, often feed in groups, sometimes constructing webs or other protection group shelters [102]. Thereon, many studies have revealed advantages of group-living for herbivores because they get a effective defense from their natural enemies [210], effective shelter-building [211], and a local safety-in-numbers from enemies [212,213] are among the benefits of aggregation [102]. On the other hand, several advantages to solitary feeding have also been proposed, such as the avoidance of induced defenses [104], density-dependent parasitoids [214] and pathogens [215].

Fears Concerning Biological Control of Weeds

When working with insects for biological control of weeds, the main fear that is had is what will happen when the natural enemy which was introduced to control the pest plant runs out of food. Will it then beginning to feed on another host plant that is useful to man. Fortunately, this assumption does not apply as arthropods and other organisms used for biological control of weeds because they have distinct dietary preferences and many of them are specific to a particular plant or a small group of related plants. The validity of this approach is demonstrated by the fact that no biological control organisms have ever become pests anywhere in the world if they have been properly screened [29].

References

1. Tipvadee A (2002) Biotechnology for insect pest control. In: Biotechnology for Sustainable Bioproduction, Elad Y, Ed., Proc. Sat. Forum, Sustainable Agricultural System in Asia, Nagoya, pp. 73-84.
2. Nava-Pérez E, Garcia-Gutiérrez C, Camacho-Báez JR, Vázquez-Montoya EL (2012) Bioplaguicidas: Una opción para el control biológico de plagas. Ra Ximhai 8: 17-29.
3. Gutiérrez-Ramírez A, Robles-Bermúdez A, Santillán-Ortega C, Ortiz-Catón M, Cambero-Campos OJ, et al. (2013) Control Biológico como herramienta sustentable en el manejo de plagas y su uso en el Estado de Nayarit, México. Revista Bio Ciencias 2: 102-112.
4. Organización de las Naciones Unidas para la Alimentación y la Agricultura (FAO) (2011) El estado de los recursos de tierras y aguas del mundo para la alimentación y la agricultura. FAO 9.
5. Servicio de información agroalimentaria y pesquera (SIAP-SAGARPA) (2011) Anuario estadístico de producción agrícola 2011. SAGARPA.
6. Hernández AA, Hansen AM (2011) Uso de plaguicidas en dos zonas agrícolas de México y evaluación de la contaminación de agua y sedimentos. Revista internacional de contaminación ambiental 27: 115-127.
7. Meehan TD, Werling BP, Landis DA, Gratton C (2011) Agricultural landscape simplification and insecticide use in the Midwestern United States. Proceeding of the National Academy of Science USA 108: 11500-11505.
8. Rebek EJ, Frank SD, Royer TA, Bográn CE (2012) Alternatives to Chemical Control of Insect Pests, In: Insecticides-Basic and Other Applications. Sonia Soloneski Ed., InTech, 9, pp 171-196.
9. González FB, Bernal IA (2000) Impacto social del uso de los plaguicidas en el mundo. Universidad de Matanzas. pp. 8-9.
10. Paredes D, Campos M, Cayuela L (2013) Conservation biological control of arthropod pests: techniques and state of art. Ecosistemas 22: 56-61.
11. Charlet LD, Olson D, Glogoza PA (2002) Biological Control of Insect and Weed Pests in North Dakota Agriculture. North Dakota State University, Fargo, North Dakota.
12. Nicholls ECI (2008) Control biológico de insectos: un enfoque agroecológico. Colombia: Editorial Universidad de Antioquia, pp. 2-124.
13. DeBach P (1974) Biological control by natural enemies. Cambridge University Press, London, UK.
14. Mahr LD, Whitaker P, Ridgway N (2008) Biological control of insects and mites: An introduction to beneficial natural enemies and their use in pest management, UW Extension, Wisconsin Madison.
15. Altieri MA (1994) Biodiversity and pest management in agroecosystems. Haworth Press, NewYork.
16. Price PW (1981) Semiochemicals in evolutionary time. In: Semiochemicals: Their role in pest control. Nordlund DA, Jones RL, Lewis WJ, Ed., J. Wiley & Sons, NY., pp. 251-279.
17. Papavizas G (1981) Biological control in crop production. Beltsville Symposia in Agricultural Research. Allanheld, Osmun Pub. London.
18. DeBach P (1964) Biological control of insect pests and weeds. Chapman and Hall Ltd., London.
19. DeBach P, Rosen D (1991) Biological control by natural enemies. Cambridge University Press, Cambridge.

20. Johnson MW (2000) Nature and scope of Biological Control. Scope of Biological Control. Notes, Biological Control of Pests, ENTO 675, UH-Manoa, Fall.

21. Stern VM, Smith RF, van den Bosch R, Hagen KS, et al. (1959) The integration of chemical and biological control of the spotted alfalfa aphid. I. The integrated control concept. Hilgardia 29: 81-101.

22. Hoskins WM, Borden AD, Michelbacher AE (1939) Recommendations for a more discriminating use of insecticides, In: Proceedings of the 6th Pacific Science Congress, Vol. 5, pp. 119-123.

23. Smith HS (1919) On some phases of insect control by the biological method. J. Econ. Entomol 12: 288-292.

24. Rabb RL (1972) Principles and Concepts of Pest Management, In: Implementing Practical Pest Management Strategies: Proceedings of a National Extension Pest Management Workshop, Purdue University, West Lafayette, Indiana, USA, pp. 6-29.

25. Caltagirone LE, Huffaker CB (1980) Benefits and Risks of Using Natural Enemies for Controlling Pests. In: Environmental Protection and Biological Forms of Control of Pest Organisms. Ludsholm B, Stackerud M, Ed., Swedish Natural Science Research Council, Stockholm, Sweden, Ecological Bulletins, No. 31, pp. 103-109.

26. Cook RJ (1987) Report of the Research Briefing Panel on Biological Control in Managed Ecosystems. National Academy Press, Washington, D.C., USA.

27. Perkins JH, Garcia R (1999) Social and Economic Factors Affecting Research and Implementation of Biological Control, In: Handbook of Biological Control. Bellows TS, Fisher TW, Ed., Academic Press, San Diego, California, USA, pp. 993-1008.

28. van den Bosch R, Messenger PS, Gutierrez AP (1982) An introduction to biological control. Plenum Press, New York and London.

29. Waterhouse DF, Norris KR (1986) Biological Control Pacific Prospects-Supplement 1. Australian Centre for International Agricultural Research Canberra. A.C.T. Monograph.

30. Jacobsen BJ1 (1997) Role of plant pathology in integrated pest management. See comment in PubMed Commons below Annu Rev Phytopathol 35: 373-391.

31. Orr D (2009) Biological Control and Integrated Pest Management, In: Integrated Pest Management: Innovation-Development. Peshin R, Dhawan AK, Ed., Springer Science, North Carolina, USA, 9: 207-239.

32. Sharkey MJ (2007) Phylogeny and Classification of Hymenoptera, In: Linnaeus Tercentenary: Progress in Invertebrate Taxonomy. Zhang ZQ, Shear WA, Ed., Zootaxa 1668: 521-548.

33. Smid HM, Wang G, Bukovinszky T, Steidle JLM, Bleeker MAK, et al. (2007) Species-specific acquisition and consolidation of long term memory in parasitic wasps. Proceedings of the Royal Society B 274: 1539-1546.

34. van Nouhuys S1, Kaartinen R (2008) A parasitoid wasp uses landmarks while monitoring potential resources. See comment in PubMed Commons below Proc Biol Sci 275: 377-385.

35. Clark ME (2007) Wolbachia symbiosis in arthropods, In: Wolbachia: A Bug's Life in Another Bug., Hoerauf A, Rao RU, Ed., Issues in Infectious Diseases, Karger S, Basel AG, Switzerland, 5: 90-123.

36. Unnikrishnan MK (2002) Biological control of insect pests. Current Sci 82: 1196-1197.

37. Horn DJ (1988) Ecological Approach to Pest Management. The Guilford Press, New York, New York, USA.

38. Howarth FG (1983) Classical biological control: panacea or Pandora's box?, Proc. Hawaii Entomol. Soc 24: 239-244.

39. Hokkanen HMT (1997) Role of Biological Control and Transgenic Crops in Reducing Use of Chemical Pesticides for Crop Protection, In: Techniques for Reducing Pesticide Use: Economic and Environmental Benefits. Pimental D, Ed., John Wiley and Sons, Chichester, West Sussex, UK, pp. 103-127.

40. Delfosse ES (2005) Risk and ethics in biological control. Biol Control 35: 319-329.

41. Obrycki JJ, Lewis LC, Orr DB (1997) Augmentative releases of entomophagous species in annual systems. Biol Control 10: 30-36.

42. Ridgway RL (1998) Mass-Reared Natural Enemies: Application, Regulation, and Needs. Thomas Say Publications in Entomology: Proceedings. Entomological Society of America, Lanham, Maryland, USA.

43. Hoddle MS1, Van Driesche RG, Sanderson JP (1998) Biology and use of the whitefly parasitoid *Encarsia formosa*. See comment in PubMed Commons below Annu Rev Entomol 43: 645-669.

44. Grant JA (1997) IPM techniques for greenhouse crops. In: Techniques for Reducing Pesticide Use: Economic and Environmental Benefits. Pimental D, Ed., John Wiley and Sons Chichester, West Sussex, UK, pp. 399-406.

45. Pottorff LP, Panter KL (2009) Integrated pest management and biological control in high tunnel production. HortTechnology 19: 61-65.

46. Collier T, van Steenwyk RA (2004) Critical evaluation of augmentative biological control. Biol Control 31: 245-256.

47. Landis DA1, Wratten SD, Gurr GM (2000) Habitat management to conserve natural enemies of arthropod pests in agriculture. See comment in PubMed Commons below Annu Rev Entomol 45: 175-201.

48. Frank SD, Shrewsbury PM (2004) Effect of conservation strips on the abundance and distribution of natural enemies and predation of *Agrotis ipsilon* (Lepidoptera: Noctuidae) on golf course fairways. Environ Entomol 33: 1662-1672.

49. Rebek EJ, Sadof CS, Hanks LM (2006) Influence of floral resource plants on control of an armored scale pest by the parasitoid *Encarsia citrina* (Craw.) (Hymenoptera: Aphelinidae). Biol Control 37: 320-328.

50. Sadof CS, O'Neil RJ, Heraux FM, Wiedenmann RN (2004) Reducing insecticide use in home gardens: effects of training and volunteer research on adoption of biological control. HortTechnology 14: 149-154.

51. Huffaker CB, Messenger PS (1976) Theory and practice of biological control, Nueva York, Academic Press.

52. Clausen CP (1978) Introduced parasites and predators of arthropod pests and weeds: A World Review, USDA Agric, Handbook 480: 545.

53. Waterhouse DF, Norris KR (1987) Biological control, pacific prospects, Melbourne, Australia, Inkata Press.

54. Cameron PJ, Hill RL, Bain J, Thomas WP (1989) A review of biological control of invertebrate pests and weeds in New Zeland 1847-1987, Commonwealth Agricultural Bureaux Institute of Biological Control, Technical Communication, No. 10, Wallinford, UK.

55. Julien MH (1992) Biological control of weeds: a world catalogue of agents and their target weeds, 3rd ed.; Wallinford, UK, Commonwealth Agricultural Bureaux International.

56. U.S. Army Corp of Engineers (2012) Biological Control. Building Strong 1-15.

57. Cook RJ, Baker KF (1983) The nature and practice of biological control of plant pathogens, American Phytopathology Society, St. Paul, Minesota.

58. Campbell R (1989) Biological control of microbial plant pathogens, Cambridge UK, Cambridge University Press.

59. Madeiros JL (1990) The barn owl: Bermuda's usung rat control expert. Montly Bulletin, Department of Agriculture, Fisheries and Parks, Bermuda, 61: 57-60.

60. Madsen H1 (1990) Biological methods for the control of freshwater snails. See comment in PubMed Commons below Parasitol Today 6: 237-241.

61. Singleton GR1, McCallum HI (1990) The potential of *Capillaria hepatica* to control mouse plagues. See comment in PubMed Commons below Parasitol Today 6: 190-193.

62. Stirling GR (1991) Biological control of plant parasitic nematodes: progress, problems and prospects. Wallinford, Oxon, UK, Commonwealth Agricultural Bureaux International.

63. Llorente J, González SE, García AAN, Cordero C (1996) Breve panorama de la taxonomía de artrópodos en México. In: Biodiversidad, taxonomía y biogeografía de artrópodos de México: hacia una síntesis de su conocimiento. Llorente BJ, García AAN, González SE, Ed., Vol. I, Instituto de Biología, Facultad de Ciencias, UNAMConabio, México, pp. 314.

64. Llorente J, Hernández BC (2008) Los artrópodos no insectos de México. In: La enciclopedia de la ciencia en México. RamírezPulido J, Ed., Libro de biología. UAM, México.

65. Llorente-Bousquets J, Ocegueda S (2008) Estado del conocimiento de la biota, en Capital natural de México, vol. I: Conocimiento actual de la biodiversidad. Conabio, México.

66. Hammond PM (1992) Species inventory. In: Global diversity. Status of the Earth's living resources. Groombridge B, Ed., World Conservation Monitoring Centre, Chapman and Hall, Londres. pp. 1739.

67. Grimaldi DA, Engel MS (2005) The evolution of insects. Cambridge University Press, Cambridge.

68. Erwin TL (1982) Tropical forests: Their richness in Coleoptera and other arthropod species Coleop. Bull 36: 7475.

69. Dicke M (2000) Annual Report Laboratory of Entomology 2000. Wageningen University, Netherlands.

70. Laing JE, Hamai J (1976) Biological control of insect pests and weeds by imported parasites, predators and pathogens. In: Theory and practice of biological control. Huffaker CB, Messenger PS, Ed., Nueva York, Academic Press, pp. 685-743.

71. Greathead DJ, Greathead AH (1992) Biological control of insect pest by parasitoids and predators: The BIOCAT database, Biocontrol News and Information 13: 61N-68N.

72. Greathead DJ (1986) Parasitoids in classical biological control. In: Insect parasitoids. Waage J, Greathead D, Ed., 13th Symposium of Royal Entomological Society of London, Londres, Academic Press, pp 289-318.

73. Badilla FF (2002) Un programa exitoso de control biológico de insectos plaga de la caña de azúcar en Costa Rica. Manejo Integrado de Plagas y Agroecología (Costa Rica) 64: 77-87.

74. Smythe RV, Coppel HC (1965) The susceptibility of Reticulitermes flavipes (Kollar) and other termite species to an experimental preparation of *Bacillus thuringiensis* Berliner. J Invertebr Pathol 7: 423-426.

75. Culliney TW, Grace JK (2000) Prospects for the biological control of subterranean termites (Isoptera: Rhinotermitidae), with special reference to *Coptotermes formosanus*. See comment in PubMed Commons below Bull Entomol Res 90: 9-21.

76. Rath AC (2000) The use of entomopathogenic fungi for control of termites. Biocontrol Sci Technol 10: 563-581.

77. Grace JK (1997) Biological control strategies for suppression of termites. J. Agric. Entomol 14: 281-289.

78. Wang C, Powell JE (2004) Cellulose bait improves the effectiveness of *Metarhizium anisopliae* as a microbial control of termites (Isoptera: Rhintermitidae). Biol Control 30: 523-529.

79. Hänel H, Watson JAL (1983) Preliminary field tests on the use of *Metarhizium anisopliae* for the control of *Nasutitermes exitiosus* (Hill) (Isoptera: Termitidae). Bull Entomol Res 73: 305-313.

80. Lai PY (1977) Biology and ecology of the *Formosan subterranean* termite, *Coptotermes formosanus*, and its susceptibility to the entomogenous fungi, *Beauveria bassiana* and *Metarhizium anisopliae*. Ph.D. dissertation. University of Hawaii, Honolulu, HI.

81. Milner RJ, Staples JA (1996) Biological control of termites: results and experiences within a CSIRO project in Australia. Biocontrol Sci Technol 6: 3-9.

82. Rosengaus RB, Lefebvre ML, Traniello JFA (2000) Inhibition of fungal conidial germination by Nasutitermes: evidence for a possible antiseptic role of soldier defensive secretions. J Chem Ecol 26: 21-39.

83. Wright MS, Lax AR, Henderson G., Chen J (2000) Growth response of *Metarhizium anisopliae* to two *Formosan subterranean* termite nest volatiles, naphthalene and fenchone. Mycologia 92: 42-45.

84. Connick WJ, Osbrink WLA, Wright MS, Williams KS, Daigle DJ, et al. (2001) Increased mortality of *Coptotermes formosanus* (Isoptera, Rhinotermitidae) exposed to eicosanoid biosynthesis inhibitors and *Serratia marcescens* (Eubacteriales: Enterobacteriaceae). Environ Entomol 30: 449-455.

85. Jones WE, Grace JK, Tamashiro M (1996) Virulence of seven isolates of *Beauveria bassiana* and *Metarhizium anisopliae* to *Coptotermes formosanus* (Isoptera: Rhinotermitidae). Environ Entomol 25: 481-487.

86. Neves PJ, Alves SB (2000) Selection of *Beauveria bassiana* (Bals.) Buill. and *Metarhizium anisopliae* (Metsch.) Sorok. strains for control of *Cornitermes cumulans* (Kollar). Brazilian Arch Biol Technol 43: 373-378.

87. Neves PJ, Alves SB (2000) Grooming capacity inhibition in *Cornitermes cumulans* (Kollar) (Isoptera: Termitidae) inoculated with entomopathogenic fungi and treated with imidacloprid. Ann Soc Entomol Brazil 29: 537-545.

88. Osbrink WLA, Williams KS, Connick JrWJ, Wright MS, Lax AR (2001) Virulence of bacteria associated with the *Formosan subterranean* termite (Isoptera: Rhinotermitidae) in New Orleans, LA. Environ Entomol 30: 443-448.

89. Rodríguez SDA (1987) Posibilidades del uso de entomopatógenos en el control biológico de insectos plagas en palma africana. Palmas 5-23.

90. Uribe-González E, Santiago-Basilio MA (2012) Contribución al conocimiento de enemigos naturales del chapulín (Orthoptera: Acridoidea) en el estado de Querétaro, México. Acta Zool Mex 28: 133-144.

91. García-Gutiérrez C, González-Maldonado MB (2009) Control biológico de plaga de chapulín (Orthoptera: Acrididae) en el norte-centro de México: Presentación. Vedalia 13: 49-50.

92. Howard JJ (1993) Temporal pattern of Resource Use and variation in Diets of Individual Grasshoppers (Orthoptera: Acrididae). J Insect Behav 6: 441-453.

93. Jenkins NE, Bateman R, Thomas MB (2003) The lubilosa programme: development of a micoinsecticide for locust and grasshopper control. Vedalia 9-10: 37-44.

94. Wendell LM (1995) Insects Pests of Small Grains. APS Press: USA.

95. García GC, Lozano GJ (2011) Control biológico de plagas de chapulín, 1st ed.; Universidad Autónoma de Zacatecas: México.

96. Gruys P (1982) Hits and misses: the ecological approach to pest control in orchards, Entomol Exp Appl 31: 70-87.

97. Abou-Awad BA, El-Banhaway EM (1986) Biological studies of *Amblyseius olivi*, a new predator of eriophyid mites infesting olive trees in Egypt (Acari-Phytoseidae). Entomophaga 31: 99-103.

98. Huffaker CB, Kennett CE (1959) A ten-year study of vegetational changes associated with biological control of Klamath weed. J Range Manage 12: 69-82.

99. McMurtry JA (1982) The use of phytoseiids for biological control: progress and future prospects. In: Recent Advances in knowledge of Phytoseidae. Hoy MA, Ed., Berkeley, Division of Agricultural Sciences, University of California, Special publication 3284: 23-48.

100. Pointier JP1, McCullough F (1989) Biological control of the snail hosts of *Schistosoma mansoni* in the Caribbean area using *Thiara* spp. See comment in PubMed Commons below Acta Trop 46: 147-155.

101. Bailey PT (1989) The milpede parasitoid *Pelidnoptera nigripennis* (Diptera: Sciomyzidae) for the biological control of the millipede *Ommatoiulus moreleti* (Diplopoda: Julida: Julidae) in Australia. Bull Entomol Res 79: 381-391.

102. Cappuccino N (2000) Oviposition Behavior of Insects Used in the Biological Control of Weeds. Proceedings of the X International Symposium on Biological Control of Weeds. Montana State University, Bozeman, Montana, USA, Neal RS, Ed., pp. 521-531.

103. Lawton JH (1979) Between the devil and the deep blue sea: on the problems of being a herbivore. Symposium of the British Ecological Society, 20: 223-244.

104. Rhoades DF (1985) Offensive-defensive interactions between herbivores and plants: their relevance in herbivore population dynamics and ecological theory. Am Nat 125: 205-238.

105. Wallner WE (1987) Factors affecting insect population dynamics: differences between outbreak and non-outbreak species. Annu Rev Entomol 32: 317-340.

106. Nothnagle PJ, Schultz JC (1987) What is a forest pest? In: Insect outbreaks. Barbosa P, Schultz JC, Ed., Academic Press, San Diego, California, USA, pp. 59-80.

107. Redfearn A, Pimm SL (1988) Population variability and polyphagy in herbivorous insect communities. Ecol Monogr 58: 39-55.

108. Hunter AF (1995) Ecology, life history and phylogeny of outbreak and nonoutbreak species. In: Population dynamics: new approaches and synthesis. Cappuccino N, Price PW, Ed., Academic Press, San Diego, CA, pp. 41-64.

109. Hanski I (1987) Pine sawfly population dynamics: patterns, processes, problems. Oikos 50: 327-335.

110. Root RB, Cappuccino N (1992) Patterns in population change and the organization of the insect community associated with goldenrod. Ecol Monogr 62: 393-420.

111. Deeker W (1992) New rabbit biological control strategies for the 90s in Australia. Vertebrate biological control centre paper, No. 1, East Melbourne, Australia, CSIRO Pub.

112. Barlow ND (1994) Predicting the effect of a novel vertebrate biocontrol agent: a model for viral-vectored immunocontraception in New Zeland possums. J Appl Ecol 31: 454-462.

113. Rusch A, Valantin-Morison M, Jean-Pierre S, Roger-Estrada J (2010) Biological Control of insect pests in agroecosystems: Effects of crop management, farming systems, and seminatural habitats at the landscape Scale: A review. Advances in Agronomy 109: 219-259.

114. Cambodia HARVEST (2013) Integrated Pest Management-Natural Enemies and Biological Control of Insects. USAID from the American People. Technical Bulletin.

115. Finke DL, Denno RF (2005) Predator diversity and the functioning of ecosystems: The role of intraguild predation in dampening trophic cascades. Ecol Lett 8: 1299-1306.

116. Rosenheim JA (2007) Special feature: Intraguild predation. Ecology 88: 2679-2728.

117. Schmitz OJ1 (2009) Effects of predator functional diversity on grassland ecosystem function. See comment in PubMed Commons below Ecology 90: 2339-2345.

118. Snyder WE, Snyder GB, Finke DL, Straub CS (2006) Predator biodiversity strengthens herbivore suppression. See comment in PubMed Commons below Ecol Lett 9: 789-796.

119. Straub CS1, Snyder WE (2006) Species identity dominates the relationship between predator biodiversity and herbivore suppression. See comment in PubMed Commons below Ecology 87: 277-282.

120. Wilby A, Villareal SC, Lan LP, Heong KL, Thomas MB (2005) Functional benefits of predator species diversity depend on prey identity. Ecol Entomol 30: 497-501.

121. Letourneau DK, Jedlicka JA, Bothwell SG, Moreno CR (2009) Effects of natural enemy biodiversity on the suppression of arthropod herbivores in terrestrial ecosystems. Annu Rev Ecol Evol Syst 40: 573-592.

122. Copping LG, Menn JJ (2000) Biopesticides: a review of their action, applications and efficacy. Pest Management Science 56: 651-676.

123. Van Driesche RG, Hoddle MS, Center TD (2007) Uso de patógenos de artrópodos como plaguicidas. In: Control de plagas y malezas por enemigos Naturales. Sección IX. Vol. 24, pp. 443-466.

124. Schöller M, Flinn PW (2000) Parasitoids and predators. In: Alternatives to Pesticides in Stored-Product. Subramanyam B, Hagstrum DW, Ed., IPM. Kluwer Academic Publishers, Boston, MA, pp. 229-271.

125. Flinn PW, Hagstrum DW, McGaughey WH (1996) Suppression of beetles in stored wheat by augmentative releases of parasitic wasps. Environ Entomol 25: 505-511.

126. Flinn PW (1998) Temperature effects on efficacy of *Choetospila elegans* (Hymenoptera: Pteromalidae) to suppress *Rhyzopertha dominica* (Coleoptera: Bostrichidae) in stored wheat. J Econ Entomol 91: 320-323.

127. Flinn PW, Hagstrum DW (2001) Augmentative releases of parasitoid wasps in stored wheat reduces insect fragments in flour. J Stored Prod Res 37: 179-186.

128. Flinn PW, Kramer KJ, Throne JE, Morgan TD (2006) Protection of stored maize insect pests using a two-component biological control method consisting of a hymenopteran parasitoid, *Theocolax elegans*, and transgenic avidin maize powder. J Stored Prod Res 42: 218-225.

129. Hussnain Z, Naheed A, Rizwana S (2007) Biocontrol or insect pests of sugarcane (*Saccharum* sp.). Pak Sugar J 22: 14-23.

130. Anonymous (1997) Proceedings of the International Colloquia on Social Insects, Vol. 3-4. St Petersburg, Russia, Socium.

131. Salazar J (1997) Internal SASEX Report on the third International Society of Sugarcane technologists Entomology Workshop, Culian, Mexico, Leslie GW, Keeping MG, Ed., Copersucar, Brazil.

132. Gomez LA (1995) Pre-congress forum discussion papers. Forum A. 1 Plant Health. Int Sugar J 97(1161): 488.

133. Pantoja N (1997) Report on the Third International Society of Sugar Cane Technologists Entomology Workshop, Culian, Mexico. In: SASA Experiment Station International Report. Leslie GW, Keeping MG, Ed., Mount Edgecombe, Durban, South Africa.

134. White WH, Regan TE (1999) Biological control of the sugarcane borer with introduced parasites in Louisiana. Sugar Journal 9: 13-17.

135. van Lenteren JC, Nell HW, Sevenster-van der LLA (1980) The parasite-host relationship between *Encarsia formosa* (Hymenoptera: Aphelinidae) and *Trialeurodes vaporariorum* (Homoptera: Aleyrodidae). IV. Oviposition behaviour of the parasite, with aspects of host selection, host discrimination and host feeding. J Appl Entomol 89: 442-454.

136. Perdikis D, Kapaxidi E, Papadoulis G (2008) Biological Control of Insect and Mite Pests in Greenhouse Solanaceous Crops. Eur J Plant Sci Biotech 2: 125-144.

137. Cappaert D (2008) The case (to date) for biological control of emerald ash borer, *Agrilus planipennis*, by a native parasitoid, *Atanycolus hicoria*e. Department of Entomology, Michigan State University, East Lansing.

138. Sánchez-Ruiz M, Fotal-Cazalla FM, Sánchez-Ruiz A, López-Colón JI (1997) El uso de insectos depredadores en el control biológico aplicado. Bol SEA 20: 141-149.

139. Gutiérrez-Ramírez A, Robles-Bermúdez A, Santillán-Ortega C, Ortiz-Catón M, Cambero-Campos OJ, et al. (2013) Control biológico como herramienta sustentable en el manejo de plagas y su uso en el estado de Nayarit, México. Revista Bio Ciencias 2: 102-112.

140. Kumar R, Muhid P, Dahms HU, Tseng LC, Hwang JS, et al. (2008) The potential of three aquatic predators to control mosquitoes in the presence of alternative prey: a comparative experimental assessment. Mar Freshwater Res 59: 817-835.

141. Caltagirone LE, Doutt RL (1989) The history of the vedalia beetle importation to California and its impact to the development of biological control. Annual Review of Entomology 34: 1-16.

142. Hunter CD (1994) Suppliers of beneficial organisms in North America, Calif. Environ. Protection Agency, PM 94-03.

143. Lövei GL1, Sunderland KD (1996) Ecology and behavior of ground beetles (Coleoptera: Carabidae). See comment in PubMed Commons below Annu Rev Entomol 41: 231-256.

144. Hance TH, Gregoire-Wibo C (1987) Effects of agricultural practices on carabid populations. Acta Phytopathol Hun 22: 147-160.

145. Carter N (1987) Management of cereal aphid (Hemiptera: Aphididae) populations and their natural enemies in winter wheat by alternate strip spraying with a selective insecticide. Bull Entomol Res 77: 677-682.

146. Mogi M1, Miyagi I (1990) Colonization of rice fields by mosquitoes (Diptera: Culicidae) and larvivorous predators in asynchronous rice cultivation areas in the Philippines. See comment in PubMed Commons below J Med Entomol 27: 530-536.

147. Axtell RC (1981) Use of predators and parasites in filth fly IPM programs in poultry housing, In: Status of biological control of filth flies. Proceedings of a workshop, University of Florida, Gainsville, Published by USDA, SEA, pp. 26-43.

148. Mills N, Schlup J (1989) The natural enemies of Ips typographus in central Europe: Impact and potential use in biological control, In: Potential for biological control of Dendroctonus and Ips Bark Beetles. Kulhavy DL, Miller MC, Ed., Texas, Nacogdoches, Center for Applied Studies, School of Forestry, Stephen F. Austin State University, pp. 131-146.

149. Drea JJ, Carlson RW (1990) Establishment of *Cybocephalus* sp. (Coleoptera: Nitidulidae) from Korea on *Unaspis euonymi* (Homoptera: Diaspididae) in the eastern United States. Proc Entomol Soc Wash 90: 307-309.

150. Hassan SA (1978) Releases of *Crysopa carnea* to control *Myzus persicae* on eggplant in small greenhouse plots. J Plant Dis Protect 85: 118-123.

151. Hagley EAC (1989) Release of *Crysopa carnea* (Neuroptera: Chrysopidae) for control of the green apple aphid *Aphis pomi* (Homoptera: Aphididae). Can Entomol 121: 309-314.

152. Ridgway RL, Jones SL (1969) Inundative releases of *Chrysopa carnea* for control of Heliothis on cotton. J Econ Entomol 62: 177-180.

153. Coll M, Bottrell DG (1992) Mortality of European corn borer larvae by natural enemies in different corn microhabitats. Biol Control 2: 95-103.

154. Ruth J, Dwumfour EF (1989) Laboratory studies on the stability of some aphid species as prey for the predatory flower bug *Anthocoris gallarum*-ulmi (Hemiptera: Anthocoridae). J Appl Entomol 108: 321-327.

155. Gravena S, Sterling WL (1983) Natural predation on the cotton leafworm (Lepidoptera: Noctuidae). J Econ Entomol 76: 779-784.

156. Sjogren RD, Legner EF (1989) Survival of the mosquito predator *Notonecta unifasciata* (Hemiptera: Notonectidae) embryos at low thermal gradients. Entomophaga 34: 201-208.

157. Meadow RH, Kelly WC, Shelton AM (1985) Evaluation of *Aphidoletes aphidimyza* (Diptera: Cecidomyiidae) for control of *Myzus persicae* (Homoptera: Aphididae) in greenhouse and field experiments in the United States. Entomophaga 30: 385-392.

158. Hagen KS, Van den Bosch R (1968) Impact of pathogens, parasites and predators on aphids, Annual Review of Entomology 13: 325-384.

159. Tracewski KT, Johnson PC, Eaton AT (1984) Relative densities of predaceous Diptera (Cecidomyiidae), Chamyiidae, Syrphidae) and their apple aphid prey in New Hampshire, USA, apple orchards. Prot Ecol 6: 199-207.

160. Holldobler B, Wilson EO (1990) The Ants, The Belknap Press of Harvard University Press, Massachusetts, Cambridge.

161. Perfecto I (1990) Ants (Hymenoptera: Formicidae) as natural control agents of pests in irrigated maize in Nicaragua. J Econ Entomol 84: 65-70.

162. Coulson JR, Klaasen W, Cook RJ, King EG, Chiang HC, et al. (1982) Notes on biological control of pests in China, 1979, In: Biological control of pest in China. Washington, DCl, United States Department of Agriculture.

163. Belloti A, Arias B (1977) Biology, ecology and biological control of the cassava hornworm (*Erinnyis ello*), In: Proceedings of the cassava protection Workshop, Cali, pp. 227-232.

164. Li YX (1989) Study on the bionomics of *Amata pascus*- a natural enemy of *Kuwanaspis pseudoleucapis*. Insect Knowledge 26: 224-225.

165. Garcia GC, González MMB (2011) Control biológico de chapulín en Durango, In: Control biológico de plagas de chapulín. Garcia GC, Lozano GJ, Ed., Universidad Autónoma de Zacatecas, México, Capítulo IV, pp. 125-137.

166. Schonbeck H (1988) Biological control of aphids on wild cherry. Allgemeine Forstzeitschrift 34: 944.

167. Riechert SE, Lockley T (1984) Spiders as biological control agents. Annu Rev Entomol 29: 299-320.

168. Riechert SE, Bishop L (1990) Prey control by an assemblage of generalist predators: Spiders in garden test systems. Ecology 71: 1.441-1.450.

169. Heinrichs EA, Aquino GB, Chelliah S, Valencia SL, Reissig WH, et al. (1982) Resurgence of *Nilaparvata lugens* populations as influenced by method and timing of insecticide applications in lowland rice. Environ Entomol 11: 78-84.

170. Gerson U, Smiley RL (1990) Acarine biocontrol agents, an illustrated key and manual, Nueva York, Chapman and Hall.

171. Hoyt SC, Caltagirone LE (1971) The developing programs of integrated control of pests on apples in Washington and peaches in California, In: Biological control. Huffaker CB, Ed., Nueva York, Plenum Press, pp. 395-421.

172. Flaherty DL, Huffaker CB (1970) Biological control of pacific mites and Willamette mites in San Joaquin Valley vineyard, part I. Role of Metaseiulus occidentalis. part II. Influence of dispersion patterns of Metaseiulus occidentalis. Hilgardia 40: 267-330.

173. Huffaker CB, Kennett CE (1956) Experimental studies on predation: 1) predation and cyclamen mite populations on strawberries in California. Hilgardia 26: 191-222.

174. Woolhouse MEJ, Harmsen R (1984) The mite complex on the foliage of a pesticide-free apple orchard: Population dynamics and habitat associations. Proc Entomol Soc Ont 115: 1-11.

175. Wallace MMH (1981) Tackling the lucerne flea and red-legged earth mite. J Agric Western Australia 22: 72-74.

176. Sorensen JT, Kinn DN, Doutt RL (1983) Biological observations on *Bdella longicornis*: a predatory mite in California vineyards (Acari: Bdellidae). Entomography 2: 297-305.

177. Wallace MMH (1954) The effect of DDT and BHC on the population of the lucerne flea, *Sminthurus viridis* (L). (Collembola), and its control by predatory mites, *Biscirus* spp. (Bdellidae). Aust J Agric Res 5: 148-155.

178. Pickett AD (1965) The Influence of Spray Programs on the Fauna of Apple Orchards in Nova Scotia. XIV. Supplement to II. Oystershell Scale, *Lepidosaphes ulmi* (L.). Can Entomol 97: 816-821.

179. LeRoux EJ (1971) Biological control attempts on pome fruit (apple and pear) in North America, 1860-1970. Can Entomol 103: 963-974.

180. Hill MG, Allan DJ, Henderson RC, Charles JC (1993) Introduction of armored scale predators and establishment of the predatory mite *Hemisarcoptes coccophagus* (Acari: Hemisarcoptidae) on latania scale, *Hemiberlesia latania* (Homoptera: Diaspididae) in kiwifruit trees in New Zeland. Bull Entomol Res 83: 369-376.

181. Chiang HC (1970) Effects of manure applications and mite predation on corn rootworm populations in Minesota. J Econ Entomol 63: 934-936.

182. Axtell RC (1963) Effects of Macrochelidae (Acarina: Mesostigmata) on House Fly Production From Dairy Cattle Manure. J Econ Entomol 56: 317-321.

183. Raghavendra K1, Sharma P, Dash AP (2008) Biological control of mosquito populations through frogs: opportunities & constrains. See comment in PubMed Commons below Indian J Med Res 128: 22-25.

184. http://research.amnh.org/vz/herpetology/amphibia/index.php

185. Pyron RA1 (2011) Divergence time estimation using fossils as terminal taxa and the origins of Lissamphibia. See comment in PubMed Commons below Syst Biol 60: 466-481.

186. Bazilescu I (1996) TED Case Studies: Frog Trade. On line: www1.american.edu/TED/frogs.htm. [Consulted 26/6/2015].

187. Rozendaal JA (1997) Mosquitoes and other biting Diptera. In: Vector Control - Methods for use by individuals and communities. Geneva: World Health Organization, pp. 7-177.

188. Mokany A1, Shine R (2003) Competition between tadpoles and mosquito larvae. See comment in PubMed Commons below Oecologia 135: 615-620.

189. Blaustein AR, Kiesecker JM (2002) Complexity in conservation: lessons from the global decline of amphibian populations. Ecol Lett 5: 597-608.

190. Williams KJ, Webb CE, Russell RC (2005) Tadpoles of four common Australian frogs are not effective predators of the common pest and vector mosquito *Culex annulrostris* skuse. J Am Mosquito Control Assoc 21: 492-494.

191. Bahena JF (2008) Enemigos naturales de las plagas agrícolas del maíz y otros cultivos. Texcoco Instituto Nacional de Investigaciones Forestales Agrícolas y Pecuarias (INIFAP) 2008: 21-27.

192. Demir I, Eryüzlü E, Demirbag Z (2012) A study on the characterization and pathogenicity of bacteria from *Lymantria dispar* L. (Lepidoptera: Lymantriidae). Turk J Biol 36: 459-468.

193. Weinzeierl R, Henn T (1991) Alternatives in Insect Management: Biological and Biorational Approaches, North Central Regional Extension Publication 401, University of Illinois at Urbana-Champaign, Illinois.

194. Lacey LA, Goettel SM (1995) Current development in microbial control of insect pests and prospects for the early 21st century. Entomophaga 40: 3-27.

195. Theilmann DA, Blissard GW, Bonning B, Jehle JA, O'reilly DR, et al. (2005) Baculoviridae In: The Eighth report of the international committee on taxonomy of viruses. Fauquet CM, Mayo MA, Maniloff J, Desselberger U, Ball LA, Ed., Elsevier, San Diego, California, pp. 177-185.

196. Kunimi Y1 (2007) Current status and prospects on microbial control in Japan. See comment in PubMed Commons below J Invertebr Pathol 95: 181-186.

197. Ahmad I, Ahmd F, Pichtel J (2011) Microbes and microbial technology: Agricultural and Environmental Applications. Springer Science Business Media pp. 415-430.

198. Moscardi F1 (1999) Assessment of the application of baculoviruses for control of Lepidoptera. See comment in PubMed Commons below Annu Rev Entomol 44: 257-289.

199. Harper JD (1978) Introduction and colonization of entornopathogens. In: Microbial control of insect pests futures strategies in pest managment system. Allen GR, Ignoffo CM, Jacques R, Ed., Gainesville, University of Florida. pp. 5-290.

200. Elad Y (1986) Mechanisms of interactions between rhizosphere microorganisms and soilborne plant pathogens, In: Microbial communities in soil. Jensen V, Kjoller A, Ed., Elsevier. London, UK, pp. 49-60.

201. Staples JA, Milner RJ (2000) A laboratory evaluation of the repellency of *Metarhizium anisopliae* conidia to *Coptotermes lacteus* (Isoptera, Rhinotermitidae). Sociobiology 36: 133-148.

202. Ignoffo CF, Garcia C (1978) In vitro inactivation of conidia of the entomopathogenic fungus *Nomuraea rilery* by human gastric juice. Environ Entomol 7: 217-218.

203. Hostetter DL, Ignoffo CM (1978) Induced epizootics: Fungi. In: Microbial Control of Insect Pests. Allen GE, Ignoffo CM, Jaques NP, Ed., University of Florida, Gainesville.

204. Henry JE (1981) Natural and applied control of insect by protozoa. Ann Rev Entom 20: 49-73.

205. http://extension.umass.edu/floriculture/fact-sheets/biological-control-using-beneficial-nematodes

206. Brusca RC, Brusca GJ (2005) Invertebrados, 2a edición. McGraw-Hill-Interamericana, Madrid, España.

207. Baker GL, Capinera JL (1997) Nematodes and nematomorphs as control agents of grasshoppers and locusts. Mem Entomol Soc Can 171: 157-211.

208. Petersen JJ (1985) Nematodes as biological control agents: Part I. Mermithidae. See comment in PubMed Commons below Adv Parasitol 24: 307-344.

209. Nault LR (1997) Arthropod transmission of plant viruses: a new synthesis. Ann Entomol Soc Am 90: 521-541.

210. Codella SG, Raffa KF (1993) Defense strategies of folivorous sawflies, In: Sawfly life history adaptations to woody plants. Wagner MR, Raffa KF, Ed., Academic Press, San Diego, CA, pp. 261-294.

211. Damman H (1991) Oviposition behaviour and clutch size in a group-feeding pyralid moth, *Omphalocera munroei* J Ani Ecol 60: 193-204.

212. Cappuccino N (1987) Comparative population dynamics of two goldenrod aphids: spatial patterns and temporal constancy. Ecology 68: 1634-1646.

213. Turchin P, Kareiva P (1989) Aggregation in *Aphis varians*: an effective strategy for reducing predation risk. Ecology 70: 1008-1016.

214. Brower LP (1958) Bird predation and foodplant specificity in closely related procryptic insects. Am Nat 92: 183-187.

215. Dwyer G (1992) On the spatial spread of insect pathogens: theory and experiment. Ecology 73: 479-494.