BIOLOGICAL CONTROL OF INSECT PESTS IN THE TROPICS

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Contents

Summary

Biological control is a pest control method with low environmental impact and small contamination risk for humans, domestic animals and the environment. Several success cases of biological control can be found in the tropics around the world. The classical biological control has been applied with greater emphasis in Australia and Latin America, with many success cases of exotic natural enemies' introduction for the control of exotic pests. Augmentative biocontrol is used in extensive areas in Latin America, especially in the cultures of sugar cane, coffee, and soybeans. The conservation of natural enemies is the biocontrol method most often reported in Africa

and Asia, where most of the major pests are native, as well as their natural enemies. Although the use of biological control encompasses large areas in every continent with tropical climate, there is a much greater use potential than what has been employed. Many exotic pests are possible targets for the classical biological control. The augmentative biological control is used only in few cultures and for a limited number of pests, and deserves greater attention. Tropical diversity is very large, indicating a source for the conservation of natural enemies. Greater popular appeal and the implementation of policies are required for a greater expression of biocontrol of insect pests in the tropics. Biological control is environmentally sound, effective on the long term and sustainable; therefore, it is the best control option.

1. Introduction

Biological control is a natural phenomenon of plant and animal regulation by their natural enemies. In the case of pest insect and mite control, the major natural enemies are other insects, known as entomophagous, or microorganisms, the entomopathogens. The entomophagous group is represented by predators and parasitoids. The entomopathogens are represented by fungi, bacteria and viruses. The populations of natural enemies and their hosts and prey tend to maintain an equilibrium in nature, and the population density of one group depends on the other’s density. However, in agricultural systems, the characteristic of low vegetable diversity and the formation of temporary systems, such as in annual crops, could be unfavorable for this equilibrium. Once this balance is broken, phytophagous insects and mites tend to reach high population densities, causing losses to the farmers. Although the use of high environmental impact techniques for the control of insect and mite pests, with the use of chemical pesticides, can present high immediate efficacy, they also present collateral effects. Insecticides and mitecides, besides being toxic for the pest organisms, are toxic to natural enemies and vertebrates, such man and domestic animals. The use of subsequent applications, oftentimes excessive, there is a trend of decreasing the natural enemies’ populations in the crops even more, worsening the damage caused by the pests. The contamination of the water table, farmers and the feedstock produced are serious problems, frequently caused the toxic action of chemical insecticides in the tropics.

Biological control is a tool used in Integrated Pest Management (IPM) for several field agricultural systems and in protected crops systems. This technology is economically viable, of low environmental impact, and does not present risks of environmental contamination. It does not present risks for human health nor for domestic animals. Moreover, it presents great potential of use on the control of disease vectors, such as dengue fever and yellow fever, which abound in tropical regions throughout the world. Although it presents so many advantages, this technique is relatively little used in tropical regions, where chemical control still performs the major role in pest control.

2. Natural Enemies of Insects and Mites

From the economic standpoint, an effective natural enemy is the one capable of regulating the population density of a pest, maintaining it below the economic damage level established for a given crop. In general, the most effective natural enemies should present the following characteristics: adaptability to environmental physical conditions changes; a certain specificity degree to a given host/prey; high capacity of population increase in relation to its host/prey; high searching capacity, especially at low densities of host/prey; seasonal synchronization with its host/prey and the ability to survive in the absence of the host/prey; and ability to change its action as function of its own density and that of the host/prey, i.e., to demonstrate reciprocal density.

Although mistakenly used as synonyms, the terms control and regulation refer to different processes and have different effects on populations. Control refers to suppression factors, which destroy a fixed percentage of the population regardless of its density. For example, the effect of a rain would eliminate (hypothetically) 80% of an aphid population, regardless if its density is 10 thousand or one million/ha; the same is expected with the use of an insecticide for pest control. Thus, a population could be quickly and substantially reduced with the use of this control; however, the control effects are short in duration and followed by a speedy resurgence of the pest.

In contrast, regulation includes the effect of environmental factors, with an action determined by the population density, i.e., a greater percentage of the population is destroyed when the population increases and vice-versa. For example, as a pest population increases, also the availability of food resources and or reproduction places for the regulating factor (natural enemy) increases, which allows the enemy to increase its own population. This increase of the natural enemy brings as a consequence an increase in pest mortality percentage, as a result of parasitism or predation, until it reaches a certain maximum level (natural enemies tend not to eliminate 100% of their hosts/preys); inversely, when the pest population decreases, the density of the natural enemy also decreases as a result of the effects of food shortage, dispersion and other factors, which results in a decrease in the percentage of pest mortality by the natural enemy. This process assures the non extinction of the host/prey, which avoids the extinction of the parasitoid, predator or pathogen. Thus, the regulator factor is perfectly inserted within the context of pest biological control.

2.1. Entomophagous

All animals that feed on insects, such as birds, frogs, lizards, are considered entomophagous. All of them have a role in insect population regulation and the quantification of the impact of each one of these enemies in nature is rather difficult. However, in agricultural systems, the major entomophagous natural enemies of insect and mite pests are other insects and mites.

2.1.1. Predators

By definition, predators are free living organisms, usually greater than their prey, and require several individuals to complete their life cycle, which are externally attacked and devoured. However, when predator insects and mites are mentioned, some changes must be made on the definition: the size of the predator in relation to prey is variable, since, though not usual for arthropods to attack in schools to dominate larger prey than each individual, it is extremely common for them to have some tools to facilitate predation. Therefore, insects which are relatively smaller than their prey can dominate them, depending on the modifications that they present. Several insects and mites are predators during their whole life cycle. However, some insects do so only during the juvenile stage or during their adulthood. Predators are basically chewers or suckers, but there can be combinations of these habits, as will be shown shortly. In general, predators can be considered generalists in relation to their prey. There are exceptions, but one predator usually hunts the most abundant insects, the most easily captured and managed that they can find in any environment.

Some insect Orders are almost exclusively of predators. The order Odonata (Dragonflies), present aquatic nymph predators, breathing through gills, and the adults are excellent fliers, capturing their prey at the borders of unpolluted lakes, and in open fields during the day. Nymphs and adults of the order Mantodea (Praying mantids) are excellent generalist hunters, hiding on leaves and inflorescences, and presenting modification in their appearance, behavior and front legs to facilitate capturing the preys. In the order Neuroptera (Lacewings) all the larvae are predators, while the adults of some species feed on pollen and nectar. Many mite species in several species are predators. Predator mites are important natural enemies of other mites, and the family Phytoseidae is the most used in biocontrol of pest mites.

In order to save energy, many predators adopt the sit and wait behavior, or the ambush. In this case, they look for places in the environment where they can stay still, observing around themselves and waiting for the passing of potential prey. This behavior maximizes energy economy, but minimized time use, since the chosen location may not have the resources required, implying in a fruitless wait. Preys of this type of predator have as defense habit the hiding habit.

Several predators adopt this foraging strategy, such as the Odonata nymphs. They remain submerged near the water surface, attached to the vegetation, waiting for their prey to pass with the water flow. If a prey passes near enough, it will be captured. Odonata adults, as well as those of Diptera, in the family Asilidae (Robber flies), have similar behavior, however, in the air. They remain sitting on leaves or twigs that allow them wide view and, with their excellent vision and flight ability, make a short and quick attack on the passing prey, at a reachable distance.

One impressive strategy found in many sit-and-wait predators is crypsis, or camouflage. It serves to make the predator invisible to their own natural enemies, especially birds (which have excellent eyesight), and also to disguise themselves and not be perceived by their prey. Predators can have the appearance of uninteresting objects for the prey, such as live or dead leaves, twigs, branches, gravel, tree bark and other shapes. They also can present attractive forms, such as flowers, attracting the prey to them. In either case, a notable example are the praying mantids, which remain disguised in the prey habitat, waiting. With their excellent vision, they perceive the incoming of a potential prey, and only attack when the distance is so short that a single “assault” will be enough to catch them, without running or flying, that is, with minimum energy expenditure. That requires important changes in the front legs, as will be seen shortly.

Several predators, however, use another prey capture strategy that requires more energy, but demands less time in the capture. These adopt the sit and wait technique, but build traps to accomplish the capture. The best examples of trap builders are the spiders and the Neuroptera larvae of the family Myrmeleontidae (Ant-lions). The spiders present several types of webs to aid the wait behavior. In contrast, the ant-lion larvae build a funnel of loose soil (Figure 1), quite common in sandy soils of tropical regions, and bury themselves in the bottom of the structure. When the prey falls in the funnel and tries to get out, it slips and ends up in the bottom, where the larva captures it, pulling it down, reducing its movements. If the prey escapes and restarts climbing the slope, the ant-lion larva throws soil and sand grains on it, making the prey slip again, until it has no more strength and is dominated. In both cases, spiders and Myrmeleontidae, that build traps, the prey defense strategy is no longer hiding, as with ambushers, but fight with the predator to try and survive.
Many predators, however, adopt active strategies for hunting their prey, instead of sitting and waiting or building traps. The organisms that adopt this strategy maximize energy expenditure, since the active search is much more energy consuming, however, they save immensely in time spent to find the needed resource. There are two possibilities of active search: random or directed.

Figure 1. Loose soil funnel constructed by the ant-lion larva to capture its preys.

Examples of predators that use the random active search strategy are the aphid eater larvae (predators of aphids), such as lady beetles (Coccinellidae) (Figure 2) and the green lacewings (Chrysopidae). These present long and developed legs, and are called campodeiform larvae, adapted to walk quickly or run. Usually they walk randomly on the plant, stopping from time to time, raising the forepart of their bodies and moving the head sideways, looking for prey. If nothing is found, they keep on walking. However, if they see a possible prey, they change behavior, try to eat the pray and, succeeding or not, start making short walks, stopping at shorter intervals to raise their heads. With this behavior, the aphid eating larvae find the aphid colonies, where they remain until the colony is devoured, or until they are satiated.

The active search for prey can be other than randomly, that is, in a directed manner. For this the predators use several signs left in the environment by their prey: it could be volatile substances released by the prey or by the plant attacked; it also could be sounds produced by the prey, as well as light stimuli (vision), tactile and the sense of smell. Usually, the directed search is more developed in parasitoids, or it could be stated that it is more studied in these organism, and, though it is less known in predators, some examples are found in very specialized predators.

Figure 2. Ladybeetle (Coleoptera: Coccinelidae).

Adapted legs to hold the prey are common in some predator groups. The praying mantids and the Mantispids (Neuroptera: Mantispidae) present as the first pair of legs this very typical adaptation, called raptorial leg: The thighs are much elongated, the trochanter allow total articulation with the femora, which are very muscular and with large prickles on the inner face, which can also be present in the tibia. These close over the femora, tightly holding the prey. Spurs on the tibia, aid in this function, in such a way that there is no escape for the captured insect. Once immobilized, the predator uses its mandible to devour the prey, tearing it in parts if necessary. This same modification can be found in predators of the families Reduviidae and Nabidae (predator assassin bugs) that feed themselves in a different manner.

Many predators, however, use their legs differently. Instead of adapting them to hold the food, use them to reach the prey more quickly: these are long legs, but not necessarily muscular. Their function is to allow a fast foraging on the area, and to run faster than the prey, after its localization. Several predator beetles present this type of leg, called ambulatory. It is the case of Carabidae (Ground Beetles and Tiger Beetles) and of Ladybeetles (Coccinellidae). The adults are good runners, and the larvae are of the type campodeiform, with long legs to allow their random search for prey in the environment.

Another fundamental predation modification is found in the mouthpiece of many insects. Those that have a bite-chewing mouthpiece, often the mandibles are well developed, sclerotized, with pointed teeth or sharp inner faces. Therefore, when the prey is reached, the simple contact of the mandible with the prey tegument is enough to cause a paralyzing injury, and no other modifications are required to hold the prey. This is found in the beetle families mentioned above.

However, deeper changes can be found in the mandibles of a very peculiar group of predators, the Neuroptera larvae: the larvae of this insect order have a very elongated mandible, which does not have the function of tearing or dilacerating; they have to be acute enough to make a small hole on the prey body. In the inner side of this acute mandible there is a groove, a deep hollow. The jawbones are also long, but in a conical shape, in manner that they connect in parallel to the inner side of the mandibles, making a channel. Through this channel, the Neuroptera inject a special saliva in the prey, with digestive properties, making the extra-oral digestion of their prey. The insect contents are dissolved by the enzymes, and the predator larvae can simply suck the digested contents, as if it were using a soda straw. The Green lacewing (family Chrysopidae), predators of aphids, young caterpillars, scales, insect eggs and other small organisms, are very active and voracious. The genera *Chrysopa* and *Chrysoperla* are widely dispersed in temperate and tropical habitats, effectively controlling several agricultural pests, especially aphids.

Besides the changes in the bite-chewer mouthpiece, adapting to the predatory activity, there are changes in other types of mouthpieces. Such is the case of sucking mouthpieces, also known as beak or rostrum, especially in the Order Hemiptera. This rostrum works as a sheath, containing inside four perforating styles, which are the tools that actually penetrate the prey. This assembly, together, allows the predator to inject a toxic saliva in the prey, paralyzing it. Then the predator sucks the prey's body contents, killing it quickly. Usually, the assassin bug predator families possess short rostrum, thick and with three segments.

Such is the case of the family Anthocoridae, an extremely important group of small predators, which are excellent natural enemies of aphids, whiteflies, young caterpillars, insect eggs and, especially, thrips. The genera *Anthocoris* and *Orius* (Figure 3) are fundamental for the biocontrol of thrips species around the world. Several *Orius* species are multiplied in the laboratory and applied under diverse climate conditions, from temperate to tropical, only to regulate thrips populations, especially in protected cultivation.

In general, the families Reduviidae, Nabidae and Phymatidae (predators of larger insects), also present rostrum of three segments. Moreover, they also present raptorial forelegs, aiding in prey domination. Giant water bugs, of several different waterbugs families (Belostomatidae, Notonectidae, Naucoridae and Gelastocoridae) present, besides a very strong rostrum, forelegs of the type raptorial, very similar to the previously described raptorial however, without the typical prickles and spurs.

Some typical families of phytophagous stink bugs, with four-segmented rostrum, have important predator examples. This is the case of the genus *Geocoris* in the family Lygaeidae, which is a predator of small insects, but presents a four-segmented rostrum. The same is found in representatives of the tribe Asopini in the family Pentatomidae, where the genera *Podisus*, *Tynacantha* and *Auchaeorrhynchus* are soybean stink bugs predators. Therefore, it is possible to find quite important stink bug predators with four-segmented rostrum.

Figure 3. Piratebug *Orius* (Hemiptera: Anthocoridae).

A third and very useful morphological modification, found in several Hymenopteran predators is the sting. Associated to it there is a poison gland, which is injected in the prey at the predation moment. This poison has special properties, maintaining the prey alive, but immobile. Thus, it can be transported to the nest, where it will be fed to the hymenopteran predator larvae. The principal predator family in this order is Vespidae (wasps) which supply their nests with several kinds of larvae (worms, borers and caterpillars), accomplishing a major task of natural biological control. Sphecidae and Scoliidae also are hymenopteran predators, with a broader feeding habit, and usually feeding alone (with no organized nests).

2.1.2. Parasitoids

The term parasitoid defines a behavior of host use that exists only in insects. Although the host can be a spider or even a snail, most of the parasitoid hosts are other insects. Parasitoids are insects that develop on or within their host. They require only one host to complete their cycle from egg to adult and kill the host when their cycle is completed (Figure 4). The parasites can use several hosts before completing their life cycle, including hosts of very different groups. Analogously, the parasites normally keep their host alive long enough to complete several parasite generations in this host. The fact that parasitoids use a single host and it is killed every time the parasitoid reaches the adult stage distinguishes parasitoids from parasites. For killing their hosts, the parasitoids are the most effective natural enemies for pest biological control.

Parasitoids use all insect development stages as hosts and can be classified according to the stage used. Egg parasitoids have their whole development within the egg of another insect. Egg-larvae parasitoid is the one that has oviposition within the egg of the host, but its development is completed in the insect's larvae. Also, there are parasitoids of larvae, pupae and larvae-pupae. The adult stage of insects is also used as host, although less frequently and by few parasitoid species.

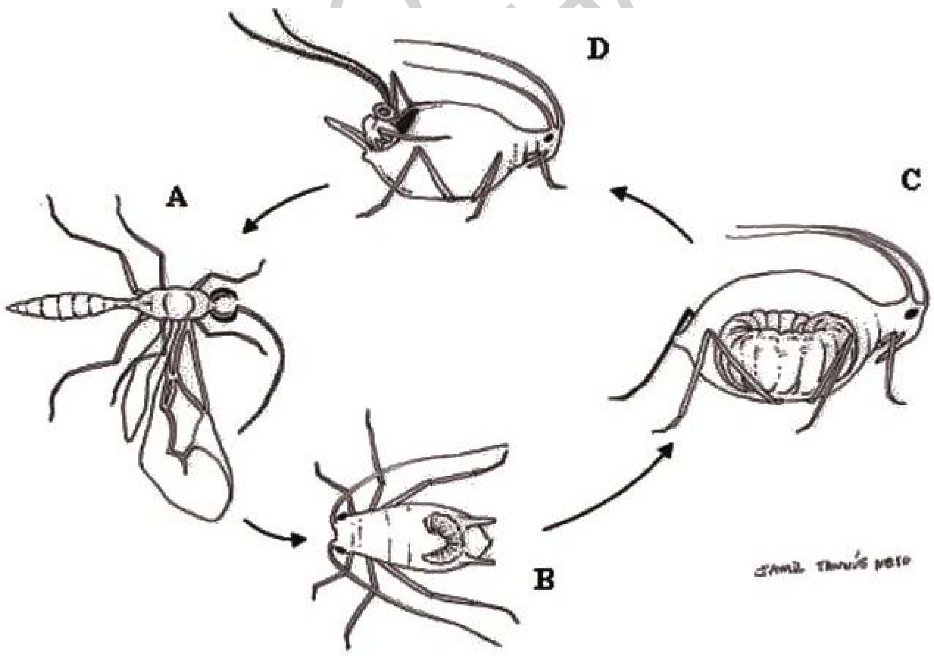

Figure 4. Life cycle of a parasitoid wasp. A - The female wasp searches for and oviposits inside (or under) its host. B - The parasitoid larva develops inside (or under) the host body. C - The parasitoid larva kills the host at the end of its development. D - The adult parasitoid wasp emerges from its host.

Other parasitoid classifications are related to the position and manner that they use their hosts. When the parasitoid develops on its host, it is called an ectoparasitoid, in contrast, when the development is inside the host, it is known as an endoparasitoid. If only a single parasitoid completes its cycle per host, then it is called solitary parasitoid; whenever more than one parasitoid develops then it is called gregarious parasitoid. Some parasitoids paralyze their hosts, idiobionts, while others complete their cycle in hosts that move, feed and grow, and are known as koinobionts parasitoids. Some parasitoids have adapted to parasitize other parasitoid. In this case, they are known as hyperparasitoids. The hyperparasitoids are present in several parasitoid families and are harmful for the pest biological control, since they reduce the parasitoid population, decreasing their effect on the pests.

Parasitoids are found in different insect orders; however, in Diptera and especially in Hymenoptera this group has become abundant. The order Diptera is composed of flies and mosquitoes and presents two fly families that are important for pest biological control. The family Phoridae is composed of several fly species that feed on organic matter. However, one group of phorids is that of ant parasitoids. These parasitoids attack one of the most important pests in Latin America, the leaf cutting ants. The phorids are being used in the biological control of fire ants in the USA, a South American pest that has threatened public health is some parts of the USA. The family Tachinidae is exclusively composed of parasitoids, concentrating in the tropical regions of the planet, and playing an important role in natural biological control of many agricultural pests. Although some tachinid species are used in biological control programs, such as the sugar cane borer, the use of this family is much below the potential it represents. The tachinids present a wide range of hosts, from insects to snails. They are parasitoids of several species of caterpillar and stink bug pests. High parasitism indices by tachinids have been found in soybean green stink bug in tropical regions, with significant reductions in the population of this pest. Greater attention should be given to this parasitoid family in tropical regions, to increase its use in pest biological control programs.

Bees, ants and wasps belong to the order Hymenoptera. The vast majority of known hymenoptera is parasitoid or had a parasitoid ancestor. It is estimated that 80% of the 600,000 known species of hymenoptera are parasitoids. At a certain moment it was thought that the hymenoptera parasitoid fauna in the tropics was much smaller than in temperate regions. It was even thought that the plethora of predators in the tropical regions would be responsible for the low parasitoid diversity. Today it is known that the probable lack of knowledge about the parasitoid fauna in the tropics is the mostly responsible for the low number of known species and that their abundance could be greater than that found in temperate regions.

The great host diversity in different habitats makes the hymenoptera parasitoids one of the most important groups for pest biological control, which are used in several biological control programs throughout the world. Since hymenoptera parasitoids attack a more restricted group of hosts, they are, in many cases, preferred in applied biological control than tachinids parasitoids or predators. Four superfamilies deserve mention: Ichneumonoidea, Chalcidoidea, Cynipoidea and Proctrotrupoidea.

Ichneumonoidea is exclusively composed of parasitoids and presents two families, Braconidade and Ichneumonidae. Both are widely distributed in the tropical regions and the braconids (Figure 5) are often used in pest biological control programs. The braconids are parasitoids of aphids, caterpillars and fly larvae. This family has been successfully used in the biological control of aphids, fruit flies and stem borers in important tropical cultures, such as citrus, sugarcane and maize.

The superfamily Chalcidoidea is composed of small wasps, which oftentimes are no longer than a few millimeters. Most of them are parasitoids or hyperparasitoids, with a few phytophagous species. Several families are important for biological control; among them Aphelidae, Eulophidae, Encyrtidae, Pteromalidae and Trichogrammatidae deserve mention. The aphelinids are parasitoids of aphids, scales and whiteflies. Some are hyperparasitoids. The genus *Aphytis* has great importance for the biological control of scale pests of citrus, and has been used in large producing areas in the USA, Africa, and South America. The genus *Encarsia* is very important for whitefly biological control, and has been used around the world for the biocontrol of greenhouse whitefly. The eulophids are leaf miners parasitoids in important tropical cultures, such as coffee, potatoes and citrus, besides the parasitoids of fruit flies. The encyrtids are scale and mealybug parasitoids, consisting of important natural enemies in coffee, citrus, pineapple and cassava. The pteromalids present a wide range of hosts, parasitizing caterpillars, beetle larvae and fly pupae. Several species of disease transmitting flies and pests in animal raising are parasitized in the tropics, during the pupae stage by pteromalids. Both encyrtids and pteromalids present hyperparasitoid species. The family Trichogrammatidae is composed of butterfly and moth egg parasitoids. The genus *Trichogramma* is the most used in the world for biological control and on several pest species in a diversity of tropical cultures, such as tomato, maize, cotton and sugar cane.

The family Figitidae deserves special mention in the superfamily Cynipoidea. The figitids are fly larvae parasitoids and are found parasitizing many important species of leaf miners and fruit flies. In tropical regions, it plays a major role in cultures such as potato, common beans and tomato, and in fruit crops, such as guava and orange. An important group of aphid hyperparasitoids is found in Figitidae, which cause serious limitations on the natural and applied biological control with the use of aphid parasitoids.

The superfamily Proctrotuproidea is highlighted for the use of egg parasitoids of the family Scelionidae. The scelionids are natural enemies of stink bugs, with great importance for the natural biological control of pest stink bugs. The use of these parasitoids in soybean stink bugs biocontrol has been used in many parts of the world.

Figure 5. Braconid parasitoid wasp.

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