Essay

Biological pest control in Mexican agriculture

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Abstract

Due to the continuous increase of the human population, the demand for food production should increase 70-100% in the following years. However, the food security of humanity is affected by several factors, among them pest insects, which are currently controlled through the application of large doses of synthetic insecticides, which generate serious problems in human health, resistance to pests, residues in foods, environmental pollution, outbreaks of secondary pests and reduction in populations of beneficial insects. Given this global scenario, these problems generate a greater demand for pest control methods that are efficient and environmentally friendly, so the objective of the present work was to address in a synthetic way the development and progress of research conducted in Mexico on the biological control of pest insects. This review focuses on technologies with a solid ecological basis for the gradual restoration of biodiversity lost in agroecosystems, so promising alternatives for pest control of great relevance in the Mexican countryside are addressed, such as the use of beneficial insects such as parasitoids, predators and entomopathogens that cause the death of pest insects, the use of sterile insect, bioinsecticides, such as microbial pesticides and other entomopathogens, incorporated plant protectors and biochemical pesticides. The demand for techniques related to the biological control of pest insects in Mexico should address the problems of transboundary, exotic, newly introduced pests and those pests that have remained for several decades in the country.

Keywords: biological control, entomopathogens, parasitoids, plant extracts, plant hormones, predators, repellent plants, volatile compounds.

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The demand for foods is one of the main objectives to be met globally, due to the increase in the population, which is estimated at 10 billion inhabitants by 2050. One of the main concerns to achieve food security is the decrease in agricultural yields generated by pest insects (Culliney, 2014). Currently, to reduce or eradicate these impacts, large doses of synthetic insecticides are applied. In Mexico, the application of synthetic pesticides increased from 97.7% in 1992 to 2016 (FAO, 2018). However, these have serious consequences in various areas such as human health, impacting up to 78% of exposed farmers or those who apply them.

Given this scenario, it is necessary to implement management programs with a solid ecological base, among the promising alternatives is the use of insects, sterile insects, and a wide spectrum of bioinsecticides. These techniques have been developed to control the pests that caused great losses in the most important crops in the country, the objective of the present work is to synthetically address the development and progress of research conducted in Mexico on the biological control of pest insects (Figure 1).

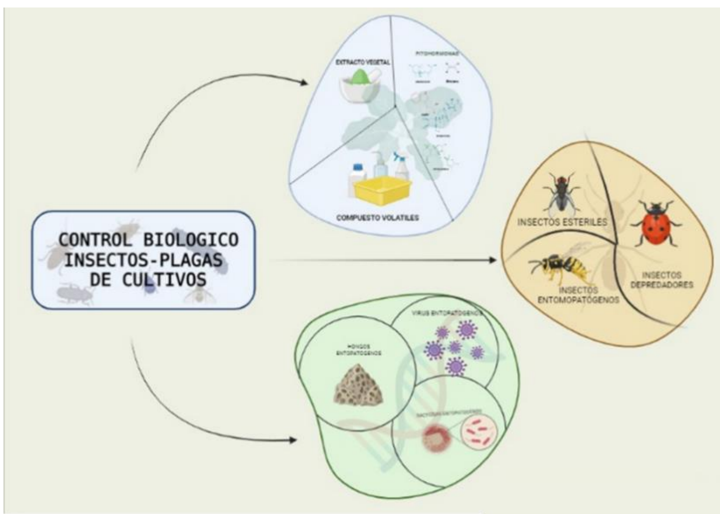

Figure 1. Biotechnologies developed for the biological control of pest insects.

Parasitoids and predators in the control of pest insects

In Mexico, the first records of the use of parasitoids and predators for the control of pest insects date from the beginning of the twentieth century. From then on, the use of various species of parasitoid Hymenoptera and Lepidoptera, and predatory Hemiptera, Diptera and Coleoptera for the biological control of exotic and native pests relevant to crops of great importance for the country, was continued through national programs implemented by government agencies (Montesinos-Matías *et al*., 2020). In 2009, the most recent national program for the control of the Asian citrus psyllid *Diaphorina citri*, vector of *Candidatus Liberibacter* asiaticus, the bacterium that causes the citrus disease Huanglongbing, began; for which a technology was developed with the Asian parasitoid *Tamarixia radiata*, and its massive release in specific areas of 19 citrus entities in Mexico (Arredondo-Bernal and Rodríguez-del Bosque, 2020).

Parasitoids are organisms that usually attack organisms of the same size, they develop inside or on the organism of interest, which, in most cases, dies when attacked, for their part, predators are organisms that consume organisms that are called prey, which are mostly smaller than their predators. There are different biological control strategies in which these parasites and predators are used, depending on the type of natural enemy to be used, their release, manipulation, or short or long term result of pest management, there are three categories: classical (introduction of an exotic biological control agent in a new environment in order for it to become long-term established and regulate an exotic pest in a sustained manner), augmentative (increase of the abundance of natural enemy species present in the area through inundative or inoculative releases) and conservative (implementation of habitat management measures to provide protection and augmentation of natural enemies to improve their effectiveness).

The insect species used for pest control in biological control programs in Mexico are produced by the National Service of Health, Safety and Agrifood Quality. In the last 20 years, in order to reduce or eliminate the use of chemical pesticides that damage the ecosystem, the incorporation of alternative techniques in agricultural production has increased the demand for effective natural enemies for the control of pest insects, mainly in the staple crops and crops with the highest production in Mexico. That is why Mexican researchers continue to focus on the search for predator and parasitoid species of pest insects new or already present in the country; for example: Cancino *et al*. (2019) evaluated the effect of augmentative releases of the hymenopteran *Diachasmimorpha longicaudata* for the suppression of *Ceratitis capitata* in coffee plantations in the border region of Guatemala, the use of augmentative biological control of this species caused a significant reduction in the values of the estimated number of flies/trap/day, being very efficient in the reduction of the population of the pest when incorporated into integrated management programs.

In addition, other species could be used, such as the larval parasitoid *D. tryoni* (Wong *et al*., 1991) or the egg parasitoid *Fopius arisanus*, more efficient in controlling *C. capitata* in coffee (Cancino *et al*., 2019). For their part, Jaraleño-Teniente *et al*. (2020), based on studies conducted in the state of Guanajuato for the control of *Spodoptera frugiperda*, a pest that limits the yield of corn, wheat and other crops, observed that predators such as mites of the genus *Balaustium*, adults of *Hippodamia convergens* and the earwig *Doru taeniatum* caused the highest mortality of *S. frugiperda* eggs, achieving together up to 63% of predation. They also recorded that the parasitism of *S. frugiperda* eggs was performed only by *Trichogramma atopovirilia* and in a very low proportion (2.8%-3.75% in corn and 2.47% in sorghum), so they propose that the use of *Trichogramma* species should be reevaluated in the established biological control programs.

Felipe-Victoriano *et al*. (2019) report that the Hymenoptera *Gryon myrmecophilum*, *Telenomus podisi* and *Trissolcus basalis* are parasitoids of eggs of the painted bug *Bagrada hilaris* in Saltillo, Coahuila. The painted bug is a key pest of crops of the *Brassicaceae* family, causing economic damage to broccoli, cabbage and cauliflower in northern Mexico. Although it is still necessary to conduct research to determine the potential of these species as biological control agents and the feasibility of augmentative, classical or inoculative methods, for the development of biocontrol strategies of this pest. Montoya *et al*. (2017), to evaluate the effect of augmentative releases of an exotic parasitoid on the diversity and abundance of native parasitoids, used *Diachasmimorpha longicaudata* for the control of fruit fly species of *Anastrepha* spp. in areas adjacent to commercial mango orchards in Chiapas.

Entomopathogens in the biological control of pest insects

Different strains of fungi, bacteria and viruses highly virulent to one or several species of pest insects are considered as entomopathogenic microorganisms, their use in the biological control of these insects is one of the sustainable alternatives that has increased in recent years. Among them, the group of entomopathogenic fungi is the most important in the control of pest insects because 80% of the diseases that occur in insects are caused by fungi. In this case, the contact of the spores of the fungi with the cuticle of susceptible insects triggers their growth through the body of the insect, which, in combination with the consumption of nutrients and the production of toxins, cause their death (Pérez, 2001), although their effectiveness depends on environmental factors.

Among the most used fungal species, due to their wide spectrum of control, are *Beauveria bassiana*, *Metarhizium anisopliae*, *Nomuraea rileyi*, *Lecanicillium lecanii* and *Paecilomyces fumosoroseus*. *B. bassiana* can infect more than 200 species of insects such as *Spodoptera frugiperda* and *Hypothenemus hampei* and *M. anisopliae* can control at least 400 species (Pacheco-Hernández *et al*., 2019). Currently in Mexico, studies on entomopathogenic fungi have focused on the control of pest insects of crops of interest, such as the Asian citrus psyllid (*Diaphorina citri*), vector of *Candidatus Liberibacter* asiaticus, which is the cause of the citrus disease Huanglongbing, where promising results have been obtained (93-100% of mortality in nymphs and 40-95% in adults) with strains of *Hirsutella citriformis*, *Paecilomyces fumosoroseus*, *Lecanicillium lecanii*, *B. bassiana* and *M. anisopliae*.

In the control of the main corn pest insects, white grubs (*Phyllophaga vetula*) and fall armyworm (*Spodoptera frugiperda*), strains of *M. anisopliae*, *Metarhizium rileyi* (Ordoñez-García *et al*., 2015), *N. rileyi* and *P. fumosoroseus* have been used, with very good results, reporting parasitism between 80-100% in eggs and larvae, and in general establishing LT50 of 1.3-6.3 days. It is important to mention that despite the 700 species of entomopathogenic fungi that are currently known, a very small number are used in the biological control of pest insects (Carrillo-Rayas and Blanco-Labra, 2009).

As for bacteria that control pest insects, the most used species are *Bacillus thuringiensis*, *Bacillus sphericus*, *Bacillus popilliae*, *Lysinibacillus sphaericus*, *Paenibacillus* spp., *Serratia entomophila* and *B. thuringiensis* is the best-known bacterial species since under stress conditions, it produces a protoxin that, in the intestine of some insects, is transformed into a toxin that causes their death (Galitsky *et al*., 2001). In Mexico, research on bacteria for the control of pest insects is limited to the use of various varieties and/or strains of *B. thuringiensis* against the tobacco worm, sugar cane borer worm and coffee berry borer, generating high mortality of these insects.

On the other hand, among insect pathogenic viruses, baculoviruses are considered safe control agents and of simple formulation and application, but the problems that still exist for their production limit their use in countries such as Mexico, although efforts have been made to obtain Nucleopolyhedrovirus isolates from dead larvae of fall armyworm (Ordoñez-García *et al*., 2015). Recently, research on the use of pathogens has included more crops; for example, in tomato, there is the work of Rios-Velasco *et al*. (2014) and that of Somoza-Vargas *et al*. (2018), who use *B. thuringiensis*, *M. anisopliae* and *B. bassiana* in their assessments.

However, the field of research and use in the biological control of entomopathogens in Mexico has been reduced to the use of 10 fungal and 1 bacterial species (Pacheco-Hernández *et al*., 2019), the same happens with the Mexican companies that produce these inputs, leaving aside a great potential to be used in the biological control of pest insects through entomopathogens, an approach that should be consolidated between the participation of Mexican research and education centers with the industrial sector.

Phytochemical compounds in the control of pest insects

The recurrent use of pesticides in agricultural production systems, in addition to generating resistance in pests, damage to human health and the environment, can collaterally affect natural enemies and cause an ecological imbalance (Ruiz-Jimenez *et al*., 2021). An alternative to this problem is the use of natural products derived from plants, generally biodegradable and that do not produce an imbalance in ecosystems (Lannacone and Reyes, 2001). Among the plant species that have been used for the control of insects in grain or seed are garlic (*Allium sativum*) for its active agents allicin and allyl propyl disulfide, castor bean (*Ricinus communis*) for its active ingredient's ricin and ricinine, and creosote bush (*Larrea tridentata*) for its active resin ingredients.

Around the world, various botanical insecticides, such as neem oil, pogam oil, rotenone and essential oils, and two main classes of insecticides, pyrethroids and neonicotinoids, which are based on insecticidal chemical compounds of plants, have been sprayed on agricultural crops (Pavela, 2016). Botanical pesticides are classified as biochemical pesticides, and are an important group of natural crop protectors, often slow-acting, that incorporate mixtures of biologically active compounds and do not develop resistance in pests. In their basic form, botanical pesticides can be raw preparations of plants, such as powders from flowers, roots, seeds, leaves, stems and essential oils. Formulas are commonly concentrated or liquid extracts (Pavela, 2016).

The botanical family Solanaceae has many species that produce compounds with insecticidal properties, for example, nicotine and capsaicin, which are used for pest control in agriculture (Gonçalves *et al*., 2021). As for botanical insecticides based on nightshade species, there are products such as Hot Pepper Wax (Vitova Insectaries, USA) formulated with *Capsicum annum* and Nico Dust based on *Nicotiana tabacum* (Pavela, 2016). Nightshades are a promising botanical family for discovering new insecticidal molecules and are widely distributed in both temperate and tropical regions, with some 2 300 species that have secondary metabolites (flavonoids, alkaloids, withanolides, capsinoids, and others) (Ohyama *et al*., 2013). The insecticidal activity of plants is attributed to the presence of secondary metabolites (Castillo *et al*., 2010). These compounds may have various mechanisms of action (Wakeil, 2013), in addition to insecticidal activity, they have a static insect effect; that is, they can act as inhibitors (Eriksson *et al*., 2008), oviposition deterrents (Dimetry, 2012), repellents (Peterson and Coats, 2001) and as growth regulators (Dimetry, 2012).

Some plant extracts are highly effective against insects and mites resistant to insecticides and organic-synthetic acaricides, due to the content of various metabolites with different modes of action, which could be used as a replacement or complement to the use of organic-synthetic pesticides, whose price, availability and application technology are beyond the reach of resource-poor farmers (Abdullahi *et al*., 2019).

In Mexico, studies on phytochemical compounds in the control of pest insects have increased greatly, such as the works of Pérez-Torres *et al*. (2017), where aqueous extracts of *Ricinus communis* with *Capsicum frutescens* alternated with soap were effective in protecting amaranth from pest damage by reducing infestation by 39.7% and increasing production by 87%; Orozco-Santos *et al*. (2016) indicated that neem, garlic and onion extracts significantly reduced *Diaphorina citri* nymphs in Mexican lime.

Repellent plants and hormones in the control of pest insects

Plants defend themselves against herbivorous insects through the combined use of direct and indirect defense mechanisms. Direct plant defense mechanisms are traits that are continuously present in the plant, which have the function of hindering the feeding, oviposition, growth and development of insects. Indirect mechanisms are constitutive or induced as a result of the joint action of mechanical damage and elicitors produced by herbivorous insects at the time of attack (Belete, 2018). Considering these defense mechanisms, in recent years plants or compounds of these have been used in order to be able to use them as sustainable alternatives for the control of pest insects due to their repellent properties. One of the most used compounds is pyrethrum, oleoresin extracted from the dried flowers of pyrethrum, *Tanacetum cinerariaefolium* (Asteraceae). The insecticidal action of pyrethrins is characterized by a rapid neurotoxic effect that affects most insects, particularly flying insects, and it causes hyperactivity and convulsions (Sun *et al*., 2020).

Rotenone is one of several isoflavonoids produced in the roots or rhizomes of the tropical legumes *Derris*, *Lonchocarpus* and *Tephrosia*. This compound is a mitochondrial poison that blocks the electron transport chain and prevents energy production (Zhang *et al*., 2020). Nicotine, an alkaloid obtained from the foliage of tobacco (*Nicotiana tabacum*) plants and related species, has a long history as an insecticide. Nicotine and two closely related alkaloids, nornicotine and anabasine, are synaptic poisons that mimic the neurotransmitter acetylcholine. In the case of neem (*Azadirachta indica*), insecticidal botanical compounds can be obtained, they actually contain more than a dozen analogues of azadirachtin, but the main form is azadirachtin. This compound blocks the synthesis and release of molting hormones (ecdysteroids) from the prothoracic gland, which causes incomplete ecdysis in immature insects. In adult female insects, a similar mechanism of action leads to sterility. In addition, azadirachtin is a potent appetite suppressant for many insects (Kim, 2021).

On the other hand, plant hormones play a fundamental role in regulating the growth, development and defense mechanisms of plants. Several plant hormones have been involved in intra- and interplant communication in insect-damaged plants. Most plant defense responses against insects are activated by signal transduction pathways mediated by jasmonic acid, salicylic acid, and ethylene. These hormones can act individually, synergistically or antagonistically, depending on the attacker (Belete, 2018). Likewise, in integrated pest management, there is great potential for plants that produce secondary metabolites since they can be used as a biological barrier in the crop and incorporated as plant residues. Also, various crop combinations drastically reduce the risk of infestation by a pest.

Associated crops favor populations of beneficial organisms, as they serve as a barrier to prevent a harmful organism from moving towards its host and increasing its population. The general concept is to use crops from different families that usually have different nutritional requirements and that are sensitive or resistant against different types of pests and diseases. Some experiments have shown that it is possible to reduce the incidence of pests by 30-60% through the planting of repellent plants, often inedible, against some specific pests, taking advantage of, for example, their aromatic property (Altieri and Nicholls, 2008). Among the plants that can be used as repellents, coriander, parsley, celery, mint, spearmint, sesame, and some grasses stand out, these being effective against butterfly larvae and nematodes (Brechelt, 2004). Plants synthesize and emit a wide variety of volatile organic compounds, which are mainly emitted by the vegetative parts of plants when exposed to biotic or abiotic stimulation, specifically as defense mechanisms to repel insects (Dong *et al*., 2016).

In Mexico, several studies on volatile compounds have been carried out in recent years, such as that of Ángeles *et al*. (2012), who detected 36 volatile organic compounds in greenhouse tomato plants infested with whiteflies; the study of Bautista and Espinosa (2013) evaluates the variation of emissions of volatile organic compounds between tomato plants in response to different damages, among others; as well as studies of the use of repellent plants for the control of grain weevils, such as the work of Alarcón *et al*. (2016) on the repellent and insecticidal activity of leaves, flowers and African tulip tree extracts in weevils and that of Pizarro *et al*. (2013) on the insecticidal effect of *Peumus boldus* powder for the control of corn weevils. However, studies on repellent plants, hormones and volatile plant compounds in pest insect control are necessary to develop new strategies for pest control.

Sterile insect technique in the control of pest insects

The current problems generated by the use of chemical pesticides have generated a greater demand for pest control methods that are efficient and environmentally friendly. The development of sustainable vector/pest control methods has become one of the most challenging issues in reducing the impact of diseases on crop pests in recent decades, all of which seek to maintain better agricultural production. Among all biological control tools, the sterile insect technique (SIT), which consists of the mass release of sterile insects to achieve the elimination or reduction of the population of a vector/pest below a certain threshold, is the most promising.

This technique is applied as part of an integrated pest management approach, offers considerable potential and has been used with great success against major pests of agricultural importance to establish pest-free areas (eradication), areas of low pest prevalence (suppression) or to maintain pest-free areas through containment or prevention. This technique is considered as an environmentally friendly pest control method for the control of plant pest insects. It consists of the mass production, sterilization and release of insects in an affected area, where sterile males mate with native females without them reproducing and thus directly impact the pest population (Anguelov *et al*., 2020). There are recent successful cases of eradication of the Mediterranean fruit fly, *Ceratitis capitata*, as well as effective programs used against the Mexican fruit fly *Anastrepha ludens*, the New World screwworm fly *Cochliomyia hominivorax* and the cactus moth *Cactoblastis cactorum* (Vreysen *et al*., 2021).

SIT is an environmentally friendly pest control technique that allows the suppression or elimination of introduced populations and the exclusion of new introductions. Reproductive sterility is normally induced by ionizing radiation, a convenient and consistent method that maintains a reasonable degree of competitiveness in released insects (Vreysen *et al*., 2021). The cost and effectiveness of a control program that integrates SIT depend on the balance between sterility and competitiveness. SIT involves mass production of the target insect pest species, sterilization, and release into the field in a sustained manner and in sufficient quantities to impact natural pest populations (Marec and Vreysen, 2019).

Sterile males find and mate with fertile females, transferring infertile sperm. There is no resulting viable offspring, which ends in a reduction of the natural pest population. Induced sterility is aimed exclusively at target species and unlike other biological control methods, no adverse impacts on organisms other than target have been reported. This technique could be used in parallel with other conventional and biological methods, such as parasitoids, predators and pathogenic insects (biopesticides) (Hendrichs, 2000).

Conclusions

Given the recent dramatic decline in insect biodiversity, investment in pest control means that do not harm the environment should be a priority. An action strategy that involves the various levels of action in decision-making must be promoted to ensure that this strategy, which has been in Mexico for some decades, becomes increasingly effective against the pests that attack crops in our country. Pest insect control is becoming more complicated, intensive crop production and lack of agricultural rotations will create more biological imbalances in the agricultural environment. Future pest control will have to be carried out without further damaging biodiversity and degrading the environment, and largely with less reliance on synthetically derived pesticides.

Disturbances to the environment as a result of the continuous expansion of travel and tourism around the world, as well as trade in agricultural products, have increased the introduction of harmful plants, insects and other harmful organisms from one area to another and it will continue to increase in the coming years, so there is no doubt that the demand for techniques related to the biological control of pest insects, in combination with each other and relying on new molecular and metabolic technologies, will have to address the problems of transboundary, exotic, newly introduced pests and those pests that have remained for several decades in the country.

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