Organismos entomopatógenos como control biológico en los sectores agropecuario y forestal de México: una revisión

Entomopathogenic organisms for pest control in the Mexican agriculture, livestock and forest sectors: a review

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Resumen
El control biológico es uno de los métodos de manejo de plagas compatibles con el ambiente, ofrece beneficios a la economía de los agricultores, protección al ambiente y a la salud de los consumidores. En esta compilación, se presenta una revisión actualizada sobre las investigaciones que se han realizado hasta el momento en el tema de organismos entomopatógenos para combate de plagas en los sectores agrícola, pecuario y forestal de México. Existen varios tipos de organismos entomopatógenos, tales como hongos, bacterias, nematodos y virus, de los cuales se mencionan las principales aplicaciones, así como las empresas que comercializan en el país productos elaborados con estos. Se resume el progreso y las investigaciones realizadas en los últimos años como componentes de las estrategias de manejo integrado de plagas en cultivos, bosques, hábitats urbanos y de importancia médica y veterinaria. Cabe resaltar el amplio interés en el estudio de hongos –principalmente Beauveria bassiana y Metarhizium anisopliae– en el sector agrícola; seguido de las aplicaciones en el sector pecuario y por último en el forestal. En cuanto a nematodos, caben resaltar los trabajos y usos, sobre todo, contra la mosca de la fruta. Las bacterias, así como los virus utilizados en el combate de plagas han sido explorados muy escasamente.

Palabras clave: Bacterias entomopatógenas, control biológico, hongos entomopatógenos, nematodos entomopatógenos, plagas, virus entomopatógenos.

Abstract
Biological control, one of the methods of pest management compatible with the environment, offers benefits to the farmers' economy, environmental protection and consumer health. This is an updated review about the research that has been carried out on entomopathogenic organisms for pest control in the Mexican agriculture, livestock and forest sectors. There are several types of entomopathogenic organisms such as fungi, bacteria, nematodes and viruses used for this purpose. It is summarized the progress and research carried out in recent years as components of the integrated pest management strategies in crops, forests, urban habitats, medical and veterinary importance. It is worth highlighting the wide interest in research of entomopathogenic fungi -mainly Beauveria bassiana and Metarhizium anisopliae- in the agricultural sector, followed by their use in the livestock and lastly in the forestry sector. More research and applications should be done regarding entomopathogenic nematodes. Bacteria, as well as viruses, applied to combat pests have been explored very rarely. The main companies that commercialize products with these organisms in the country are also listed.

Key words: Entomopathogenic bacteria, biological control, entomopathogenic fungi, entomopathogenic nematodes, plagas, virus entomopathogenic.
Introduction

The indiscriminate use of synthetic pesticides is the direct cause of the resistance of different organisms, and therefore of the loss of their effectiveness. Given this situation, it is common to increase the doses and prepare mixtures of several pesticides, often more toxic, so that the problem of resistance, far from being solved, becomes worse. Chemical control of pests also produces other effects such as secondary pest outbreaks, pest resurgence and decreased populations of natural enemies. From this situation, it is necessary to develop methods of pest management compatible with the environment, one of which is biological control.

Biological control offers, at the same time, benefits to the farmers' economy, environmental protection and consumer health. In addition, it has contributed to the development of agriculture in Mexico and many countries (Arredondo, 2008). Technicians and producers, intuitively, have realized that the use of biological control allows them to fight pests against which entomophageal or entomopathogenic species are available, at a lower cost than the expenditures generated by the use of chemical pesticides. Therefore, it is currently assumed that this alternative constitutes (from its economic, environmental and ecological virtues) the most desirable strategy for the management of populations of agricultural, livestock and forest pests.

Contrary to what one might think, this is not a new strategy for crop protection in Mexico. Its history covers almost 100 years, during which some important successes have been obtained. However, since 1990, the role of biological control has been formalized at the federal and state levels of government and within the academic community. In 1991, the Centro Nacional de Referencia para el Control Biológico (CNRCB) National Reference Center for Biological Control (CNRCB, for its acronym in Spanish) was inaugurated in Tecomán, Colima, Mexico, and was recognized by the International Organization for Biological Control as an international reference center. The CNRCB has the mission of developing and establishing biological control strategies for regulated pests, for this purpose it generates and provides alternative technology to the use of chemical pesticides. Likewise, it contributes with phytosanitary programs or campaigns in which the use of beneficial organisms as
agents of biological control is promoted, in order to strengthen the health of plant crops in Mexico (CNRCB, 2018).

The Servicio Nacional de Sanidad, Inocuidad y Calidad Agroalimentaria (Senasica) (National Agrifood Service of Health, Safety and Quality (Senasica, for its acronym in Spanish in Mexico), a decentralized institution of the Secretaría de Agricultura y Desarrollo Rural (Sader) (Department of Agriculture and Rural Development (Sader, for its acronym in Spanish in Mexico), has the responsibility of monitoring and controlling plant and animal health, food safety and inspection of agricultural and animal products at national borders and inspection points. Fortunately, the authorities of these institutions have considered and supported biological control when planning governmental responses to emerging pest problems, so, in emergency situations, Senasica asks the CNRCB reference center to evaluate possible pest options that represent important threats to the country (Trevor et al., 2013).

There are more and more scientists and researchers involved in the disciplines related to this task, so in 1989 the Sociedad Mexicana de Control Biológico (Mexican Society of Biological Control) was established; this group holds an annual conference, as well as courses and workshops that attract several hundred people each year. However, the development of biological control as a scientific discipline and as a technology for crop protection is still under development (SMCB, 2018).

In the near future it is envisioned that the use of biological control will increase as a result of the globalization of the economy, and openness to international trade, so the use of bioinsecticides and biopesticides will be the norm, since the latter with organisms Entomopathogens have become a good tool for the biological control of many insect pests and are receiving more attention due to their environmentally friendly nature, their effectiveness against pests and their easy mass production protocols. The term entomopathogens refers to microorganisms capable of causing a disease to the pest insect, leading to its death after a short incubation period. There are several types of entomopathogenic organisms, such as fungi, bacteria, nematodes and viruses (García and González, 2013).
Information on entomopathogenic organisms as pest control agents is described below, which may be of interest to generations of producers, students, scientists and scholars in Mexico and thereby stimulate research and practice of biological control, as a responsible option for improving the environment.

**Entomopathogenic fungi**

Entomopathogenic fungi are the most important group in the biological control of pest insects. Virtually all insects are susceptible to diseases caused by these fungi. When their spores come into contact with the cuticle of susceptible insects, they germinate and grow directly through it towards the inside of their host's body. Therefore, the fungus proliferates throughout the body of the insect producing toxins and consuming nutrients from the insect, and eventually destroys it. At the beginning of the infection, symptoms may or may not be observed, but the insect begins to lose mobility and appetite. After seven or ten days, it dies due to nutritional deficiency (Pérez, 2004).

The diseases they cause are known as *muscardinas*, a term that was first applied to *Beauveria bassiana* (Bals.-Criv.) Vuill. The color of the conidia is very variable, hence, there are different names such as green *muscardina*, for *Metarhizium anisopliae* (Metchnikoff) Sorokin and Nomuraea rileyi (Farlow) Samson, and red *muscardina* for *Paecilomyces fumosoroseus* (Wize) Brown & Smith. The use of these organisms is one of the best alternatives used in biological control because it is economical, simple and ecologically sustainable. However, it is essential to provide adequate temperature and humidity conditions to achieve its purpose. In addition, when it is intended to be used as bioinsecticides, it is necessary to carry out an exhaustive characterization of isolates in order to select those with high virulence and good conditions for field application. This characterization includes studies referring to the mode of infection (Godwin and Shawgi, 2000; Arredondo et al., 2008; Caballero, 2014). Nowadays it is important to carry out studies on the molecular and biochemical determinants related to the specificity of the fungus to the host.
It is well known that *B. bassiana* infects more than 200 species of insects of different orders, which include pests of economic importance such as the *cogollero* worm (*Spodoptera frugiperda* (J.E. Smith)), borer worm (*Diatrea magnifactella* Dyar, 1911), coffee drill (*Hypothenemus hampei* Ferrari, 1867), among others. While *M. anisopliae*, with a broader spectrum of toxicity, has been found infecting between 300 and 400 species of lepidoptera, beetles, dipterans and homoptera (Table 1).

**Table 1.** Main entomopathogenic fungi used for pest control in the agricultural sector.

| Fungi | Plague                        | Crop            | Reference                        |
|-------|-------------------------------|-----------------|----------------------------------|
|       | *Coffee drill: Hypothenemus hampei* Ferrari, 1867 (Coleoptera: Scolytinae) | Coffee          | Gerónimo, 2016                   |
|       | *Coffee drill: H. hampei* Ferrari, 1867 | Coffee          | Díaz and Roblero, 2007           |
|       | *Predators of Diaphorina citri* Kuwayama: *Ceracrysa valida* Banks and *Eremochrysa punctinervis* McLaughlan | Citrus          | Gándarilla *et al.*, 2013         |
|       | *Ligus bug: nymphs of Lygus lineolaris* Palisot de Beauvois | Strawberry      | González *et al.*, 2010          |
|       | *Mexican bean beetle: Epilachna variversis* Mulsant | Beans           | Castrejón, 2017                  |
|       | *Grasshoppers: Brachystola magna* Girard and *B. mexicana* Bruner | Beans           | Lozano and España, 2006          |
|       | *White fly: Bemisia tabaco* Gennadius | Green vegetables | Ruiz, 2009                       |
|       | *Plague insect of Jatropha curcas L. fruit: Pachycoris torridus* Scopoli | Jatropha curcas | Chávez, 2016                     |
|       | *Codling moth: Cydia pomonella* L. | Apple           | Solís, 2006                      |
|       | *Opuntia weevil: Metamasius spinolae* Gyllenhal | Edible opuntia  | Sánchez *et al.*, 2016           |
|       | *Opuntia weevil: M. spinolae* Gyllenhal | Edible opuntia  | Tafoya, 2004                     |
|       | *White fly* *B. tabaci* Gennadius | More than 500 ornamental species | García *et al.*, 2013            |
|       | *Agave weevil: Scyphophorus interstitialis* Gyllenhal | Agave hard liquors | Aquino, 2006                     |
|       | *Borer worm: Diatrea magnifactella* Dyar, 1911 | Sugar cane      | Castro *et al.*, 2013            |
|       | *Bacteria Candidatus Liberibacter* spp. | Citruses        | Melián *et al.*, 2016            |
|       | **Blind hen larvae:** *Phyllophaga crinita* (Burm.) (Coleoptera: Melolonthidae) | Maize, green areas, golf greens | Nájera, 2005                     |
|       | **Blind hen:** *Phyllophaga vetula* Horn | Maize           | Hernández *et al.*, 2011         |
|       | **Scale insects or scales (Sap sucking insects): Aulacopsis tubercularis** Newstead | Mango           | Pérez-Salgado, 2013              |
|       | **Fruit flies:** *Anastrepha obliqua* (Macquart) | Mango           | Díaz-Ordaz *et al.*, 2010        |
|       | **Potatoe psyllid:** *Bactericera cockerelli* Šulc. | Potatoe         | Villegas, 2017                   |
|       | **Borer worm:** *D. magnifactella* Dyar, 1911 | Sugar cane and maize | Buenosaires, 2013              |
|       | **Grasshoppers:** *Sphenarium purpurascens* (Charpentier) and *Melanoplus differentialis* (Thomas) (Orthoptera: Acrididae) | Maize and beans | Tamayo, 2009.                    |
|       | **Central American locust:** *Schistocerca piceifrons piceifrons* Walker | Maize, sorghum, beans, sugar cane, soy, cotton, sesame, bananas and peanuts. | Barrientos, 2005 |
Entomopathogenic fungi against agricultural pests

Table 1 summarizes the main research studies carried out in the most important crops in the country where entomopathogenic fungi were used. The extensive study of *Beauveria bassiana* strains is outstanding, especially in the fight against pests such as the coffee drill, in which Gerónimo *et al.* (2016) observed a pathogenic effectiveness of 100% at 144 h in this crop; Díaz and Roblero (2007) recorded that the optimal time for the application of the fungus is in July, before the drill enters the coffee fruit.

From Mexico's interest in citrus production, Pérez-González *et al.* (2013) conducted studies against the Asian citrus psyllid (*Diaphorina citri* Kuwayama) in which they used the fungus *Hirsutella citriformis* Speare; Mellín *et al.* (2016) with *Paecilomyces fumosoroseus* and Hernández *et al.* (2007) with *Lecanicillium lecanii* (Zimm.) Zare &
W. Gams.; in addition to studies conducted with *B. bassiana* and *M. anisopliae* by Gandarilla et al. (2013). In all these studies, the strains analyzed were considered as promising for the development of biological control technology of *D. citri*, as in the case of *M. anisopliae*, which caused 93-100% mortalities in nymphs, while in adults the Mortality range ranged from 40 to 95% (Mellín et al., 2016).

*Phyllophaga vetula* Horn, 1887, known in Mexico as blind hen and the sprout worm (*Spodoptera frugiperda*) are two of the main corn pests that have been studied to combat them with *M. anisopliae* with which the highest level of virulence was recorded and where the treatments recorded a mortality of 80% at 30 days (Nájera, 2005). Buenosaires (2013) reported an LC$_{50}$ of 2.0518 × 10$^8$ conidia ml$^{-1}$. In a similar way, strains of the *N. rileyi* fungus have been explored, which parasitized 100% of the neonatal larvae of these pests, with a TL$_{50}$ between 4.1 and 6.3 d, as well as strains of *P. fumosoroseus* that parasitized between 92.5 and 98.8%, with a TL$_{50}$ between 2.5 and 4.3 d (Lezama et al., 2004); these same authors in 2006, published a more extensive study where they evaluated other strains of entomopathogenic fungi concluding that the strains of *M. anisopliae*, *P. fumosoroseus* and *P. javanicus* (Friederichs & Bally) Brown & Smith, were highly virulent in eggs and larvae with a mortality of 94 and 100%, and a TL$_{50}$ of 1.3 to 3.3 d. The strains of *B. bassiana* had a very variable virulence, with a parasitism between 3-90% in eggs and 54-100% in larvae (Lezama et al., 2006b). On the other hand, Ruiz et al. (2012) concluded in their studies that *S. carpocapsae* (1.500 JI plant$^{-1}$) in combination with *M. anisopliae* (2 × 108 spores plant$^{-1}$) are recommended for the control of larvae of *P. vetula*.

**Entomologic fungi against livestock plagues**

In studies with entomopathogenic fungi for the control of pests in the livestock sector (Table 2), it is observed that *M. anisopliae* and *B. bassiana*, mainly, have been effective for the control of pests of cattle ticks, fleas of dog, bugs bream, grasshopper and *dengue* transmitting mosquitoes. There are few records in which other strains of entomopathogenic fungi such as *Trichoderma*, *Cordyceps* or *Isaria* have been explored, to name a few.
Table 2. Main entomopathogenic fungi used for pest control in the livestock sector.

| Fungi | Plague | Animal | Reference |
|-------|--------|--------|-----------|
| *Beauveria bassiana* (Bals.-Criv.) Vuill. | Kissing bug: *Meccus pallidipennis* Stål, 1872 | Kissing bug, causative of Chagas disease | Zumaquero, 2014 |
| | *Ctenocephalides canis* Shaftesbury, 1934 | Dog flea | Pacheco, 2015 |
| | Grasshopper (Orthoptera: Acrididae) | Grasshopper | García and González, 2009 |
| *B. bassiana* (Bals.-Criv.) Vuill. and *Metarhizium anisopliae* (Metchnikoff) Sorokin | Garrapata *Rhipicephalus microplus* Canestrini, 1888 | Cattle ticks | Rivera-Oliver et al., 2013 |
| | Tick: *Rhicephalus* (Boophilus) *microplus* | Cattle ticks | Bautista, 2017 |
| | Flea: *C. canis* Shaftesbury, 1934 | Dog flea | Rivera-Ramírez, 2013 |
| *M. anisopliae* (Metchnikoff) Sorokine and *Isaria fumosorosea* Wize | Kissing bug: *M. pallidipennis* Stål, 1872 | Kissing bug, causative of Chagas disease. | Flores, 2016 |
| *Trichoderma*, *M. anisopliae* (Metchnikoff) Sorokine, *A. aculeatus* Lizuka, *G. virens* Corda | Dengue’s vector: *Aedes aegypti* Linnaeus, 1762 | Dengue’s vector: *Aedes aegypti* Linnaeus, 1762 mosquitoes | Molina et al., 2013 |

Among the most economically important pests in this sector is the cattle tick (*Rhipicephalus microplus* Canestrini, 1888); according to Rivera (2013), the use of entomopathogenic fungi such as *M. anisopliae* and *B. bassiana* are found to be pathogenic for the three, eight, and 17-day-old eggs of the insect, and it is accentuated the younger the tick egg is. For Bautista (2017), *M. anisopliae* and *B. bassiana* are an alternative for the control of adult ticks in the XIII Maya region of Chiapas and the Ríos region of the state of Tabasco, Mexico.

Entomopathogenic fungi have been tested to combat mosquitoes that transmit serious diseases. Thus, Flores et al. (2016) investigated the effects of *M. anisopliae* and *I. fumosorosea* Wize on nymphs of *Meccus pallidipennis* Stål, 1872, which is the main triatomine vector of Chagas disease in Mexico, in terms of insect survival and immune response. Zumaquero et al. (2014) studied an isolation of *B. bassiana* from San Antonio Rayón, Puebla, Mexico and its entomopathogenic effects in *Meccus pallidipennis*, from which they concluded that this strain was 100 % virulent. A strain of *T. longibrachiatum* showed high entomopathogenic activity on larvae and adult females of *Aedes aegypti* Linnaeus, 1762 mosquitoes, which are Dengue vectors; therefore, this fungus can be a good candidate to be developed as a bioinsecticide.
Rivera-Ramírez et al. (2013) documented that *B. bassiana* and *M. anisopliae* are pathogens for dog fleas (*Ctenocephalides canis* Shaftesbury, 1934) under laboratory conditions; and Pacheco et al. (2015) assessed the pathogenicity of two strains of *B. bassiana* at concentrations of 10, 15 and 20 % mineral oil, sterile water and Tween 80, inoculated by immersion on *C. canis*; it turned out that the treatment formulated at 10 % recorded mycosis of 86.3 % on fleas, confirming that it was the most pathogenic.

### Entomologic fungi against forest plagues

There are very few reports in Mexico regarding the use of entomopathogenic fungi to combat forest pests (Table 3). Due to the economic importance of red cedar wood, *B. bassiana* has been one of the most studied fungi against the combat of the meliaceous borer (*Hypsipyla grandell* Zeller, 1898).

#### Table 3. Main entomopathogenic fungi used for pest control in the forestry sector.

| Fungi                                      | Plague                      | Affected species     | Reference          |
|--------------------------------------------|-----------------------------|----------------------|--------------------|
| *Beauveria bassiana* (Bals.-Criv.) Vuill. and *Metarhizium anisopliae* (Metchnikoff) Sorokin | *Hypsipyla grandella* Zeller, 1898 | *Cedrela odorata* L. | Díaz et al., 2009  |
| *B. bassiana* (Bals.-Criv.) Vuill.         | *H. grandella* Zeller, 1898  | *Cedrela odorata* L. | Caballero, 2014    |
|                                            | Meliaceae borer: *H. grandella* Zeller, 1898 | Precious woods | Barrios et al., 2017 |
| *Trichoderma* sp                           | Bark beetles: *Dendroctonus* spp. | *Pinus* spp.        | Gijón et al., 2015 |
|                                            | Bark beetles: *Dendroctonus* spp. | *Pinus greggii* Engelm. ex Parl. | Arriola et al., 2016 |

Díaz et al. (2009) evaluated chemical insecticides such as Novaluron, Pyrethroids, Amitraz (Ovicides) and Carbofuran, as well as *Beauveria bassiana* and *Metarhizium anisopliae*, an organic insecticide based on Neem (*Azadirachta indica* A. Juss.) and a control against this forest pest. His conclusion was that the treatments with *B. bassiana* and *M. anisopliae* had the same degree of control as the chemicals, with the advantage of not being contaminants and of not representing a risk of toxicity for the personnel that applies.
For Caballero (2014), the inoculation of *B. bassiana* in washed, disinfected and conserved larvae of *H. grandella* in an area with a controlled climate at 22 °C, was achieved as they colonized them, which means that in the laboratory stage they *B. bassiana* was found effective for the control of *H. grandella*. On the other hand, Barrios *et al.* (2017) selected two native strains of *B. bassiana* for use in the control of this pest, and the evaluation of pathogenicity of the two isolates demonstrated mortality on third instar larvae at a dose of $1 \times 10^8$. According to the authors, these strains could have a high potential to be used in the nursery or in the field for the integrated management of the borer, since they recorded 92.84 % dead of after five days, on average.

Regarding the applications of *Trichoderma* for the biological control of the pest of debarkers in laboratory conditions, the contribution of Gijón *et al.* (2015) showed, by statistical analysis, that a strain of this fungus caused 100 % mortality of these insects. The following year, Arriola *et al.* (2016) announced their results on the same fungus to combat the same pest in the *Sierra Gorda* Biosphere Reserve, Qro.; there, five treatments were applied to *Pinus greggii* Engelm. ex Parl. trees, which consisted of three concentrations of conidia / milliliter: high $3.6 \times 10^8$, average $9 \times 10^7$ and low $5 \times 10^7$, a control based on a commercial product with *M. anisopliae* ($5 \times 10^9$) and an absolute water control. The highest concentration was the one that recorded the most severe mortality.

**Entomopathogenic nematodes**

Entomopathogenic nematodes (NEP) in the *Steinernema* and *Heterorhabditis* genera are potent agents for biological control. Nematodes parasitize their hosts (in this case plague insects) by direct penetration through the cuticle to the hemocele or by penetration through natural openings (spiracles, mouth and anus). The infection can be passive or active, and the way in which the infection process continues will depend on the species of nematode that attacks the insect. In the case of *Steinernema* and *Heterorhabditis*, once the infective juvenile manages to penetrate the hemocele, it
releases the associated bacteria, which reproduces in the hemolymph of the host and causes death (Pérez, 2004).

In the last decade, substantial advances have been made in its research and application, since the number of target pests that are susceptible to NEPs has continued to increase (Table 4). The progress is also due to the advances in the technology of its production, which use in vivo and in vitro systems, and the new methods of application (injections, sprays, etc.), as well as advances in genomics, nematode symbiont -bacteria interactions and ecological relations.

**Table 4.** Main entomopathogenic nematodes used for pest control in Mexico.

| Nematode                                | Plague                                      | Affected species | Reference            |
|-----------------------------------------|---------------------------------------------|------------------|----------------------|
| **Steinernema carpocapsae** Weiser, 1955 (All and Tecomán strains), Steinernema feltiae Filipjev, 1934, S. glaseri Steiner, 1929 (cepa NC), S. riobravis Cabanillas, Poinar & Raulston, 1994 and Heterorhabditis bacteriophora Tecomán** | Seven-day larvae, prepupa and pupa of the core worm: Spodoptera frugiperda (J.E. Smith) | Maize, golf greens  | Molina, 1996          |
| **S. feltiae Filipjev, 1934**           | Third stage larvae of the Mexican fruit fly: Anastrepha ludens Loew, 1873 | Plague of several fruit species, in citrus and mango in particular | Lezama et al., 1996b |
| **H. bacteriophora Tecomán**            | Mexican fruit fly: A. ludens Loew, 1873     | Fruit plagues    | Toledo et al., 2001  |
|                                         | Fruit fly: Anastrepha obliqua Macquart, 1835 | Mango, plum and guava | Toledo et al., 2005  |

In Mexico, *Steinernema carpocapsae* Weiser, 1955 has been declared efficient in the combat of larvae of the third stage of Mexican fruit fly (*Anastrepha ludens* Loew, 1873), which is a pest that attacks especially citrus and mango. Lezama *et al.* (1996b) demonstrated that this pest is susceptible to varying degrees to various tested nematodes. *S. riobravis* Cabanillas, Poinar & Raulston, 1994 and *S. carpocapsae* All strain killed 90 % of the larvae and pupae; *H. bacteriophora* Poinar 1975 NC strain killed 82.5 %; *Steinernema feltiae* Filipjev, 1934, 81.25 %; the *S. carpocapsae* Tecomán strain caused 76 % mortality, while *H. bacteriophora* Tecomán and *S. glaseri* Steiner, 1929, 52.5 %. These results suggest that the *S. riobravis* and *S. carpocapsae* strain species have potential as biological control agents against the fruit fly.
On the other hand, Toledo et al. (2001) assessed the parasitic capacity of *S. feltiae* in laboratory conditions on larvae of *A. ludens* of third stage, and pupae of five and 12 days of age, in three soils of different texture and three temperature regimes. Their results showed that there was no difference when the nematodes were applied to the soil before or after the larvae. The pupae were not susceptible to attack. In adults who emerged and left through the treated soil, parasitism was only 10%. Later, in 2005, the same authors studied this plague, but this time using another nematode: *H. bacteriophora* (Toledo et al., 2005). These studies allowed them to describe the effect of temperature, soil texture and depth of the host on the ability of nematode infection in third stage larvae of *Anastrepha obliqua* Macquart, 1835 and, although the potential of the nematode was demonstrated to infect and kill *A. obliqua* larvae, it was evident that there was an important difference in the susceptibility of the six-day-old larvae, compared to those of eight days.

In a study on the control of the maize core worm with nematodes, Molina et al. (1996) identified that *S. carpocapsae* strain All, *S. riobravis* and *H. megidis* Poinar, Jackson & Klein, 1988 have potential as biocontrol agents against *S. frugiperda*. The LC$_{50}$ varied from 1.5 to 20.6 and 3.4 to 37.2 mL$^{-1}$ nematodes, for larvae and prepupes, respectively, and in their studies the cumulative mortality in pupae was 5-43% with the concentration of 100 mL$^{-1}$ nematodes.

### Entomopathogenic bacteria

The greatest success in the microbial control of insects in the world has been achieved by *Bacillus thuringiensis* Berliner, 1915 (Bt). The crystals (Cry) that it produces under stress conditions are aggregates of a large protein (130-140 kDa) that is not really active in itself (it is a protoxin) as it is insoluble. When protoxin is subjected to very basic conditions (pH $>9.5$) such as those existing in the intestines of some insects, it is solubilized and transformed by means of the insect proteases into an active toxin of about 60 kDa. This is the toxin known as "δ-Bt endotoxin", which acts by binding to receptors of epithelial cells of the intestine of the insect, which leads to the
formation of pores and osmotic lysis of the cells that finally they cause their death (Galitsky et al., 2001).

At present, the gene responsible for the production of this endotoxin has been introduced into tobacco, corn, tomato, cotton, potato, beet and cabbage plants, among other crops, giving rise to genetically modified (GMO) crops. The wide acceptance of GM crops, especially in the United States of America, has increased the yield per hectare and the income of farmers in these countries. The first success achieved in this field was obtained in 1987 when it was possible to produce transgenic tobacco plants capable of producing by themselves a toxin of the bacteria \textit{B. thuringiensis}, which had lethal effects for certain phytophagous insects (Rubio and Fereres, 2005).

Some entomopathogenic bacteria have been developed for the control of commercial scale insect pests, among which the subspecies of \textit{Bacillus thuringiensis}, \textit{Lysinibacillus sphaericus} Neide, 1904, \textit{Paenibacillus} spp. and \textit{Serratia entomophila} Grimont. The subspecies \textit{B. thuringiensis kurstaki} is the most commonly used for the control of insect pests of crops and forests, and the subspecies \textit{israelensis} and \textit{L. sphaericus} of \textit{B. thuringiensis} are the main pathogens used for the control of pests of medical importance (Ponce et al., 2003). These pathogens combine the advantages of chemical pesticides and biological control agents: they are fast acting, easy to produce at a relatively low cost, easy to formulate, have a long shelf life and allow delivery using conventional application equipment and systems systemic (\textit{i.e.} in transgenic plants) (De la Rosa et al., 2005; Camacho et al., 2017; García et al., 2018).

There is very little experience on the use of bacteria for pest control in Mexico, and these are limited to the use of \textit{Bacillus thuringiensis} for tobacco worm control, the sugarcane borer worm and the coffee drill in the agricultural sector (Table 5), and for control of the mosquito vector of the \textit{dengue} virus.
In the case of the coffee drill (*Hypothenemus hampei* Ferrari, 1867), its most susceptible stage was its first larval instar, with an average lethal time average of 6.4 ± 1.8 days (De la Rosa et al., 2005). For the sugarcane borer worm (*Diatraea considerata* Heinrich, 1931), Camacho et al. (2017) managed to isolate eight strains of dead insects in agricultural fields, which were from *B. thuringiensis* and observed a high mortality with the strains of interest.

From different tobacco plants obtained from southeastern Mexico, García et al. (2018) made isolates, from which they selected bacterial colonies of *Bacillus thuringiensis*, which caused 100 % mortality of *Manduca sexta* Linnaeus larvae, 1763 at 96 h of exposition. In other studies against tobacco pests the toxicity of *Bacillus thuringiensis* ssp Kenyae was demonstrated against eight species of Lepidoptera, one of Coleoptera and one of Diptera (Barboza et al., 1998).

On the other hand, against the control of the mosquito vector of the *dengue* virus (*Aedes aegypti*), in 2003 the bioinsecticide Vectobac 12 AS was formulated based on *B. thuringiensis var israelensis* Barjac, 1978 (Bti). The product was applied in pipe trucks that deliver water to several communities in the metropolitan area of *Monterrey*, NL; in this way, the people received it with the means to interrupt the biological cycle of the virus. Bti proved effective as a larvicide against *A. aegypti* even in the presence of chlorine in the water. However, the results showed that the efficiency of Bti applied in pipes was reduced mainly due to water temperature, larval density, sunlight and the effect of association with filter organisms (Ponce et al., 2003).
Entomopathogenic virus

Insect pathogenic viruses are an important source of microbial control agents, particularly for the control of lepidopteran pests. Baculoviruses are accepted as safe, easily mass-produced, highly pathogenic and easily formulated and applied control agents. New baculovirus products are appearing in many countries and gaining greater market share. However, the absence of a practical *in vitro* mass production system, higher production costs, limited persistence after application, slow death rate and high host specificity contribute to its restricted use in control of pests. Overcoming these limitations are key research areas for which progress could open the use of insect viruses to much larger markets. The Baculoviridae family is the most numerous and studied of entomopathogenic viruses. The use of the *Anticarsia gemmatalis* Hübner 1818 NPV nucleopolyhedrovirus, (AgMNPV) to control *A. gemmatalis* in soybeans in Brazil was a successful program and was considered the most important in the world (Nava, 2012).

Biopesticides based on entomopathogenic organisms

Currently, there are several companies mainly in Holland, France, Italy, Great Britain and Russia, which sell products for biological control with entomopathogenic organisms (Rubio and Fereres, 2005). The fact of marketing products with living organisms has its limitations, among which stand out:

- Problems with patents (since living organisms are not patented, a specific use of them can be patented, but the difficulty lies in the fact that commercializing a living organism makes it easy for anyone to use it as a starter culture to multiply or replicate the product and this cannot be controlled).
- High production costs, since specialized labor is required with the consequent increase in the final product. This means that biocontrol agents generally have a higher price than chemical pesticides.
Short shelf life of the product, this is because ultimately they are living organisms that require a certain temperature and humidity to survive.

Too specific in some cases, which requires the use of several different biocontrol agents to control pests that usually appear in the same crop. Instead, chemical pesticides usually control several pests at the same time.

Complex application as it requires qualified personnel.

Until almost 10 years ago, the commercial production of bioinsecticides and other biological control agents in Mexico was carried out in at least 68 companies and 25 states, although these numbers have now increased; they reproduce entomopathogenic fungi (mainly *Beauveria bassiana* and *Metarhizium anisopliae*; entomopathogenic bacteria (*Bacillus thuringiensis*) and nematodes (*Heterorhabditis bacteriophora* and *Steinernema carpocapsae*). These microorganisms are the basic active ingredients in the formulation of bioinsecticides (Table 6); carrier, an inert material as a support, and adjuvants, as well as compounds that promote and maintain the viability of the active ingredient and protect it from UV radiation, rain, moisture and dehydration, which facilitates its handling, application and effectiveness (García and Mier, 2010).
**Table 6. Main Mexican companies that sell bioinsecticides based on entomopathogenic organisms.**

| Company                                      | Products based on:                                                                 | Location of the company by state |
|----------------------------------------------|------------------------------------------------------------------------------------|----------------------------------|
| Agrobiológicos del Noroeste, S. A de C.V.    | *Beauveria bassiana* (Bals.-Criv.) Vuill., *Metarhizium anisoplae* Metchnikoff Sorokin var. *anisoplae*, *Isaria fumosorosea* Wize, *Lecanicillium lecanii* (Zimm.) Zare & W. Gams., *Paecilomyces lilacinus* (Thom) Samson and *Trichoderma harzianum* Rifai | Sinaloa                          |
| Bioagris                                     | Biological fungicides with spores of *Trichoderma viride* Pers., or *Beauveria bassiana* (Bals.-Criv.) Vuill., or *Metarhizium anisoplae* Metchnikoff Sorokin or spores of *Paecilomyces lilacinus* (Thom) Samson | Ciudad de México                 |
| Bioamin                                      | Biological insecticides based on spores of *Beauveria bassiana* (Bals.-Criv.) Vuill., *T. harzianum* Rifai and *T. viride* Pers., *Bacillus thuringiensis* Berliner and entomopathogenic fungi of the *Paecilomyces* genus | Saltillo, Coahuila               |
| Biotecnología Agroindustrial                 | *Bacillus thuringiensis* Berliner and three entomopathogenic fungi, *Subtilis*, *Trichoderma* and *Bacillus subtilis* (Ehrenberg) | Morelia, Michoacán               |
| Bio- Zentla                                  | *B. bassiana* (Bals.-Criv.) Vuill., *M. anisoplae* (Metchnikoff) Sorokin, microrna, *Paecilomyces fumosoroseus* (Wize) Brown & Smith | Zentla, Veracruz                 |
| Desarrollo Lácteo, S.P.R de R.L.             | *Spalangia endius* Walker, *Trichogramma pretiosum* Riley, *Chrysoperla carnea* Stephens, *B. bassiana* (Bals.-Criv.) Vuill., *I. fumosorosea* Wize, *M. anisoplae* Metchnikoff Sorokin var. *anisoplae* and *T. harzianum* Rifai | Gómez Palacio, Durango           |
| EcoAgro                                      | Biological plagues control, bioinsecticides and biofertilizant production, biocellosológicos procedures applied to agriculture | Sinaloa                          |
| FMC Agroquímica de México S. de R. L. de C.V.| Agrochemical products in México and Latin America. Biofungicide based on a very singular bacterial strain that belongs to *B. subtilis* (Ehrenberg) | Zapopan, Jalisco                 |
| Grupo Solena                                 | *Azospirillum brasilense* Tarrand, Krieg & Döbereiner, *B. subtilis* (Ehrenberg), *B. thuringiensis* Berliner var. *kurstaki*, *B. thuringiensis* Berliner var. aizawai, *B. thuringiensis* Berliner var. israeliensis, *B. bassiana* (Bals.-Criv.) Vuill., *Glomus intraradices* Blasz, *Wubet*, *Renker* & *Buscot*, *M. anisoplae* (Metchnikoff) Sorokin, *Paecilomyces lilacinus* (Thom) Samson, *Rhizobium* sp., *Streptomyces* spp., *T. harzianum* Rifai | León, Guanajuato                 |
| Microida Innovación Agrícola S.A de C.V.     | *A. brasilense* Tarrand, Krieg & Döbereiner, *Azotobacter sp.* , *B. subtilis* (Ehrenberg), *B. thuringiensis* Berliner var. *kurstaki*, *B. thuringiensis* Berliner var. aizawai, *B. thuringiensis* Berliner var. israeliensis, *B. bassiana* (Bals.-Criv.) Vuill., *Glomus intraradices* Blasz, *Wubet*, *Renker* & *Buscot*, *M. anisoplae* (Metchnikoff) Sorokin, *Paecilomyces lilacinus* (Thom) Samson, *Rhizobium* sp., *Streptomyces* spp., *T. harzianum* Rifai | Morelia, Michoacán               |
| Minerales y nutrientes Plantifor             | *Bacillus megatherium* de Barry, *B. subtilis* (Ehrenberg), *Beauveria bassiana* (Bals.-Criv.) Vuill., *Metarhizium*, *Trichoderma* spp. | San Luis Potosí                  |
| Organismos beneficios.com                    | Entomopathogenic fungi                                                              | Jalisco                          |
| Profertinnova                                | Natural bioinsecticide for biological control 100 % organic made from entomopathogenic fungi (*Metarhizium* sp. and *Verticillium* sp.). | Estado de México                |
| Profungi                                     | Entomopathogenic fungi, biological insecticides                                     | Sinaloa                          |
| SummitAgro México                           | Biological insecticides based on *Bacillus thuringiensis* Berliner var. *kurstaki* serotipo 3a, 3b and *Bacillus subtilis* (Ehrenberg) | Ciudad de México                 |
| Tierra de Monte                              | *Beauveria bassiana* (Bals.-Criv.) Vuill., *Metarhizium*, *Paecilomyces*, *Thricoderma*, entomopathogenic microorganism concentration and stimulators of the vegetal immune system | Querétaro                        |
| Ultraquímica Agrícola, S.A de C.V.           | *B. bassiana* (Bals.-Criv.) Vuill., *I. fumosorosea* Wize, *L. lecanii* (Zimm.) Zare & W. Gams., *Metarhizium anisoplae* Metchnikoff Sorokin var. *acridium* and *M. anisoplae* Metchnikoff Sorokin var. *anisoplae*, *P. lilacinus* (Thom) Samson, *Trichoderma* spp., *Bacillus subtilis* (Ehrenberg) and *B. thuringiensis* Berliner | Morelos                          |
| Valent de México                            | Bioinsecticides based on *Bacillus thuringiensis* Berliner spp. *kurstaki*         | Zapopan, Jalisco                 |
The regulations in Mexico (NOM-032-FITO-1995) (Sagarpa, 2015) indicate that for the registration and commercialization of bioinsecticides, official provisions must be complied with and the opinion of different institutions that regulate crop health, the risk of the substances that are used as pesticides must be met, as well as care for the environment and human health (García and González, 2013). Likewise, it is necessary to carry out biosecurity studies and risk of the environmental impact of the agents used in biological control (qualitative and quantitative evaluation), environmental monitoring of these organisms and assessment of their effect on non-target organisms.

**Conclusions**

Based on the impact of climate change, the intense exploitation in agricultural, livestock and forestry production systems, the use of extensive monocultures without management in forests and worldwide commercial opening, it is necessary to promote biological control of pests (bioinsecticides and biological agents with entomopathogenic organisms) as well as assessing the environmental impact of these products with more tests under field conditions to identify the effects of biotic and abiotic factors on efficacy and persistence, since these are also useful to agriculture, they favor human health and the environment. On the other hand, it is also essential for these new biological products to design more efficient production, formulation and mass delivery systems to supply a growing market.

From the review carried out in this work, it can be concluded that as in the rest of the world, studies of entomopathogenic fungi for combating agricultural, livestock and forest pests abound in Mexico. Special attention has been given to *Beauveria bassiana* and *Metarhizium anisopliae* in recent years, since its toxicity has been very effective against a broad spectrum of pests, in addition to the fact that stable commercial products with mixtures of entomopathogenic organisms have been developed to enhance their insecticidal action. However, further studies are required to overcome the current difficulties related to the production and development of these bioinsecticides.
To a much lesser extent, nematodes, bacteria have been addressed and very little interest has been given to viruses against pests, so it is suggested to promote these lines of research and their use in integrated pest management programs; in particular, strategies that incorporate entomopathogenic organisms in combination with predators and parasitoids should be defined to ensure compatibility and maximize their effectiveness.

**Conflict of interests**

The authors declare no conflict of interests.

**Contribution by author**

Ma. de Lourdes Pacheco Hernández: literature review and writing of the manuscript; J. Francisco Reséndiz Martínez and Víctor J. Arriola Padilla: review and correction of the manuscript.

**References**

Aquino B., T., J. Ruiz V. y M. Iparraguirre C. 2006. Control biológico del picudo negro (*Scyphophorus interstitiales* Gyllenhal) con nematodos y hongos entomopatógenos en agave en Oaxaca, México. Rev. UDO Agrícola 6(1): 92- 101.

Arredondo B., H. C. y L. A. Rodríguez del B. 2008. Casos de control biológico en México. Mundi Prensa México. México, D. F., México. 423 p.

Arriola P., V. J., J. Rentería B., A. R. Gijón H., L. Ramírez H. y M. E. Romero S. 2016. Evaluación de *Trichoderma* sp., como agente de control biológico de *Dendroctonus* spp. (Curculionidae: Scolytinae) en la Sierra Gorda de Querétaro, México. Entomología Mexicana 3: 239–243.

Barboza C., J. E., J. E. López- M. y J. E. Ibarra. 1998. Caracterización de una cepa mexicana de *Bacillus thuringiensis* ssp. keniae: Un análisis de su baja toxicidad hacia lepidópteros. Vedalia 5: 3-12.
Barrientos L., J., D. M. Hunter, J. Ávila V., P. García S. y J. V. Horta V. 2005. Control biológico de la langosta centroamericana Schistocerca piceifrons piceifrons Walker (Orthoptera: Acrididae) en el noreste de México. Vedalia 12 (2): 119-128.

Barrios D., B., S. Reyes S., G. Vázquez H., J. M. Barrios D., N. P. Castro G., R. Berdeja A. y J. M. E. Aguilar L. 2017. Patogenicidad in vitro de Beauveria bassiana sobre Hypsipyla grandella Zeller (Lepidoptera: Pyralidae) barrenador del cedro rojo. Entomología mexicana 4: 265–270.

Bautista G., A., R. Pimentel S. y A. Gómez V. 2017. Control biológico de Rhicephalus (Boophilus) microplus con hongos entomopatógenos. Revista Iberoamericana de Ciencias Biológicas y Agropecuarias 6(12): 1-30. Doi: 10.23913/ciba.v6i12.68.

Buenosaires Á., A. I., G. Peña C. y L. A. Rodríguez del B. 2013. Determinación de la virulencia de la cepa 148 de Bacillus thuringiensis y Ma-156 de Metarhizium anisopliae sobre Diatraea magnifactella DYAR. A. Entomología mexicana 12(1): 298-300.

Caballero C., W. J. 2014. Producción y aplicación del hongo Beauveria bassiana en el laboratorio de control biológico del ITZM. Instituto Tecnológico de la Zona Maya. Quintana Roo, México. 33 p.

Camacho M., R., E. M. Aguilar M., H. Quezada, O. Medina C., G. Patino L., H. M. Cárdenas C. and R. Ramos P. 2017. Characterization of Cry toxins from autochthonous Bacillus thuringiensis isolates from Mexico. Boletín Médico del Hospital Infantil de México. 74 (3): 193-199. Doi: 10.1016/j.bmhimx.2017.03.002.

Castrejón A., J. E., G. Núñez M., M. M. Iracheta, R. Gómez F., F. Tamayo M., J. A. Ocampo H. and P. Tamez G. 2017. Beauveria bassiana blastospores produced in selective medium reduce survival time of Epilachna varivestis Mulsant larvae. Southwestern Entomologist 42(1): 203-220. Doi: 10.3958/059.042.0119.

Castro O., I. R., A. Fonseca G., A. G. Trejo L., V. M. Hernández V., L. A. Rodríguez del B. y L. P. Lina G. 2013. Evaluación de seis cepas de hongos entomopatógenos sobre Diatraea magnifactella DYAR (Lepidoptera: Crambidae). Entomología mexicana 12(1): 430-433.
Ceceña D., C., D. González M., O. Grimaldo J., P. Ruvalcaba S., O. Tzintzun C. y D. Durán H. 2017. Eficacia de entomopatógenos en el control de la Mosca Blanca (*Bemisia argentifolii*, Bellows y Perring) en algodonero en el DDR 014. Cuerpo Académico de Biotecnología Agropecuaria (UABC- CA-165). Universidad Autónoma de Baja California. Omnia Publisher SL. Baja California, BC, México. 68 p. Doi: 10.3926/oms.366.

Centro Nacional de Referencia de Control Biológico (CNRCB). 2018. Introducción al CNRCB. https://www.gob.mx/senasica/acciones-y-programas/centro-nacional-de-referencia-de-control-biologico-103097 (24 de noviembre de 2018).

Chávez, B. Y., J. C. Rojas, J. F. Barrera y J. Gómez. 2016. Evaluación de la patogenicidad de *Beauveria bassiana* sobre *Pachycoris torridus* en laboratorio. Southwestern Entomologist 41(3):783-790. Doi:10.3958/059.041.0320.

De la Rosa, W., M. Figueroa and J. E. Ibarra. 2005. Selection of *Bacillus thuringiensis* strains native to Mexico and active against the coffee berry borer *Hypothenemus hampei* (Ferrari) (Coleoptera: Curculionidae: Scolytinae). Vedalia 12 (1): 3-9.

Díaz V., V. M. y D. Roblero J. 2007. Épocas de aplicación del hongo *Beauveria bassiana* (Bals.) Vuill. para control de *Hypothenemus hampei* Ferr. Revista Quehacer Científico en Chiapas. Tuxtla Gutiérrez, Chis., México. pp. 42-47.

Díaz M., E., A. O. Gutiérrez, P. A. Contreras G., R. R. Rivera y L. R. Centeno E. 2009. Control del barrenador de las meliáceas en plantaciones de cedro en la península de Yucatán. In: IV Reunión Nacional de Innovación Agrícola y Forestal. Inifap. Sección de Plantaciones Forestales y Sistemas Agroforestales. Saltillo, Coah., México. p. 364.

Díaz-Ordaz, N. H., N. Pérez and J. Toledo. 2010. Pathogenicity of three strains of entomopathogenic fungus on *Anastrepha obliqua* adults (Macquart) (Diptera: Tephritidae) under laboratory conditions. Acta Zoológica Mexicana (n. s.), 26(3): 481-494. Doi:10.21829/azm.2010.263796.

Flores V., A. L., M. Cabrera B., C. Toriello, M. I. Bucio T., P. M. Salazar S. and A. Córdoba A. 2016. Survival and immune response of the Chagas vector *Meccus pallidipennis* (Hemiptera: Reduviidae) against two entomopathogenic fungi, *Metarhizium anisopliae* and *Isaria fumosorosea*. Parasit Vectors 9:176-187. Doi: 10.1186/s13071-016-1453-1.
Galitsky, N., V. Cody, A. Wojtczak, D. Ghosh, J. R. Luft, W. Pangborn and L. English. 2001. Structure of the insecticidal bacterial delta-endotoxin Cry3Bb1 of Bacillus thuringiensis. Acta Crystallographica Section D. 57 (Pt 8):1101–9. Doi:10.1107/S0907444901008186. PMID 11468393.

Gandarilla P., F. L., I. Quintero Z., R. Rodríguez G., M. Elías S., C. F. Sandoval C. y L. J. Galán W. 2013. Efecto de hongos entomopatógenos sobre Ceraeochrysa valida y Eremochrysa punctinervis (Neuroptera: Chrysopidae) depredadores de Diaphorina citri Kuwayama (Hemiptera: Liviidae) en México. Entomología Mexicana 12(1):415-419.

García de L., S. y T. Mier. 2010. Visión general de la producción y aplicación de bioplaguicidas en México. Sociedades Rurales, Producción y Medio Ambiente 10(20): 37-63.

García G., C. y M. B. González M. 2009. Control biológico de plaga de chapulín (Orthoptera: Acrididae) en Durango, México. Vedalia 13 (2): 79-83.

García G., C. y M. B. González M. 2010. Uso de biosecticidas para el control de plagas de hortalizas en comunidades rurales. Ra Ximhai 6(1): 17-22.

García G., C. y M. B. González M. 2013. Síntesis sobre el uso de bioinsecticidas y otros agentes de control biológico de plagas en México. Vedalia 14 (1): 35-42.

García R., E., R. Pérez P., B. L. León E. y L. Pliego M. 2013. Patogenicidad de Metarhizium anisopliae y Beauveria bassiana sobre mosca blanca (Bemisia tabaci). Revista Mexicana de Ciencias Agrícolas 4(6):1129-1138. Doi: 10.29312/remexca.v0i6.1277

García R., A., A. Reyes R., E. Ruíz S. y J. E. Ibarra. 2018. Aislados nativos de del sureste de México. Revista Mexicana de Ciencias Agrícolas 9(3): 539- 551. Doi: 10.29312/remexca.v9i3.1213.

Gerónimo T., J. C., M. Torres de la C., M. Pérez de la C., A. de la C. P., C. F. Ortiz G. y S. Cappello G. 2016. Caracterización de aislamientos nativos de Beauveria bassiana y su patogenicidad hacia Hypothenemus hampei, en Tabasco, México. Revista Colombiana de Entomología 42 (1): 28-35. Doi: 10.25100/socolen.v42i1.6666.

Gijón H., A. R., Z. Trejo S., C. M. López G., L. Ramírez H., V. J. Arriola P. e I. M. Pérez G. 2015. Caracterización y efectividad de Trichoderma spp. sobre insectos descortezadores de pino. Entomología Mexicana 2: 293-299.
Godwin, P. K. and H. Shawgi. 2000. Entomogenous fungi as promising biopesticides for tick control. Experimental and Applied Acarology 24: 913–926. Doi:10.1023/a:1010722914299.

González S., M. G., J. C. Salazar T., F. Jaimes A., S. Ramírez A. y R. González S. 2010. Eficacia de Beauveria bassiana (Balsamo) Vuillemin en el control de Lygus lineolaris (Palisot de Beauvois) en fresa. Revista Chapingo Serie Horticultura 16(3): 189-193. Doi: 10.5154/r.rchsh.2010.16.024.

Hernández T., I., A. Berlanga P., J. I. López A., J. Loera G. y E. Acosta D. 2007. Evaluación de hongos entomopatógenos para el control del pulgón café de los cítricos, Toxoptera citricida (Kirkaldy), en México. INIFAP. CIRNE. Campo Experimental General Terán. Folleto Científico Núm. 1. General Terán, N L, México. 19 p.

Hernández V., V. M., Z. Cervantes E., F. J. Villalobos, L. L. García y G. Peña C. 2011. Aislamiento de hongos entomopatógenos en suelo y sobre gallinas ciegas (Coleoptera: Melolonthidae) en agroecosistemas de maíz. Acta Zoológica Mexicana (n.s.), 27(3): 591-599. Doi:10.21829/azm.2011.273777.

Lezama G., R., R. Alatorre R. y F. Sánchez. 1994. Evaluación de cepas de Nomuraea rileyi y Paecilomyces fumosoroseus contra Spodoptera frugiperda (Lepidoptera: Noctuidae). Vedalia 1: 19-22.

Lezama G., R., R. Alatorre R., L. F. Bojalil J., J. Molina O., M. Arenas V., M. González R. and O. Rebolledo D. 1996a. Virulence of five entomopathogenic fungi (Hyphomycetes) against Spodoptera frugiperda (LepidopterA: Noctuidae) eggs and neonate larvae. Vedalia 3: 35-40.

Lezama G., R., J. Molina O., M., L. Contreras O., M. González R., A. Trujillo de la L. y O. Rebolledo D. 1996b. Susceptibilidad de larvas de Anastrepha ludens (Diptera: Tephritidae) a diversos nematodos entomopatógenos (Steinernematidae y Heterorhabditidae). Vedalia 3: 31-34.

Lezama G., R., J. Molina O., M., O. Rebolledo D., A. Trujillo de la L., M. González R. and S. Briceño R. 1997. Evaluation of entomopathogenic fungi (Hyphomycetes) against Anthonomus fulvipes (COLEOPTERA: CURCULIONIDAE) in organically grown Barbados cherry trees. Vedalia 4: 25-30.

Lozano G., J. y M. P. España L. 2006. Enemigos naturales y control biológico de Brachystola magna (Girard) y B. mexicana (Bruner) (Orthoptera: Acrididae) con Beauveria bassiana en Zacatecas, México. Vedalia 13 (2): 91-96.
Mellín R., M. A., J. A. Sánchez G., A. M. Cruz Á., R. Montesinos M. y H.C. Arredondo B. 2016. Patogenicidad de cepas de hongos entomopatógenos sobre *Diaphorina citri* Kuwayama en condiciones de laboratorio. Southwestern Entomologist, 41(3):791- 800. Doi:10.3958/059.041.0321.

Molina O., J., J. J. Hamm, R. Lezama G., L. F. Bojalil J., M. Arenas V. and M. González R. 1996. Virulence of six entomopathogenic nematodes (*Steinernematidae* and *Heterorhabditidae*) on immature stages of *Spodoptera frugiperda* (Lepidoptera: Noctuidae). Vedalia 3: 25-30.

Molina T., L., D. Mejía M., L. A. Cisneros V. y M. G. Vázquez M. 2013. Infección de mosquitos *Aedes aegypti* (Diptera: Culicidae) vectores del dengue por hongos entomopatógenos. Entomología Mexicana 12(1): 446- 451.

Nájera R., M. B., M. García M., R. L. Crocker, V. Hernández V. y L. A. Rodríguez del B. 2005. Virulencia de *Beauveria bassiana* y *Metarhizium anisopliae*, nativos del occidente de México, contra larvas de tercer estadio de *Phyllopaga crinita* (Coleoptera: Melolonthidae) bajo condiciones de laboratorio. Fitosanidad 9(1): 33-36.

Nava P., E., C. García G., J. R. Camacho B. y E. L. Vázquez M. 2012. Bioplaguicidas: Una opción para el control biológico de plagas. Ra Ximhai 8(3b): 17-29.

Pacheco B., L. R, M. Moreno R., L. A. Arriola M., M. Valencia P., R. Lezama G., E. Corona B. y C. A. Angel S. 2015. Formulados de *Beauveria bassiana* (BALSAMO) Vuillemin sobre *Ctenocephalides canis* (Curtis): resultados preliminares. Entomología Mexicana 2: 272-277.

Pérez C., N. 2004. Manejo ecológico de plagas. Centro de Estudios de Desarrollo Agrario y Rural- CEDAR. La Habana, Cuba. 292 p.

Pérez-González, O., M. G. Maldonado-Blanco, R. I. Torres-Acosta, R. Rodríguez-Guerra, M. Elías-Santos y J. I. López-Arroyo. 2013. Evaluacion de aislados mexicanos de *Hirsutella citriformis* Speare contra *Diaphorina citri* Kuwayama (HEMIPTERA: LIIVIDAE) en laboratorio. Entomología Mexicana 12(1):381- 386.
Pérez-Salgado, J., M. D. Ángel-Ríos, A. Arteaga-Deloya, E. Hernández-Castro y A. Damián-Nava. 2013. Hongos entomopatógenos y extractos vegetales contra escama blanca (*Aulacaspis tuberculatus* Newstead) en cultivo de mango en San Luis La Loma, municipio de Tecpan de Galeana, Gro., México. Entomología Mexicana 12(1):452- 455.

Ponce, G., A. E. Flores, M. H. Badii, I. Fernández, T. González, M. L. Rodríguez y J. A. Chiu. 2003. Evaluación de *Bacillus thuringiensis israelensis* (Vectobac 12 AS) sobre la población larval de *Aedes aegypti* en el área metropolitana de Monterrey N.L., México. Revista Salud Pública y Nutrición 4(3): 1-6.

Pulido-Herrera, A., E. Zavaleta-Mejía, L. Cervantes-Díaz y O. Grimaldo-Juárez. 2012. Alternativas de control en la pudrición radical de cebolla para el Valle de la Trinidad, Baja California. Revista Mexicana de Ciencias Agrícolas 3(1): 97-112. Doi:10.29312/remexca.v3i1.1483.

Rivera-Oliver, R., C. A. Angel-Sahagún, A. M. Cruz-Avalos, R. Lezama-Gutiérrez, M. Canchola-Ramírez y J. Molina-Ochoa. 2013. Patogenicidad de hongos entomopatógenos sobre huevos de diferente edad de la garrapata *Rhipicephalus microplus*. Entomología Mexicana 12(1): 346-350.

Rivera-Ramírez, L. V., C. A. Angel-Sahagún, M. Valencia-Posadas, J. E. Ortega-Palomares y M. Canchola-Ramírez. 2013. Evaluación de hongos entomopatógenos sobre pulgas *Ctenocephalides canis*: resultados preliminares. Entomología Mexicana 12(1): 356- 359.

Rubio S. V. y A. Fereres C. 2005. Control biológico de plagas y enfermedades de los cultivos. Centro de Ciencias Medioambientales (CCMA-CSIC). Departamento de Protección Vegetal. Madrid, España. pp. 1- 16.

Ruiz S., E., A. T. Rosado C., W. Chan C., J. Cristóbal A. y R. Munguía R. 2009. Patogenicidad de *Beauveria bassiana* (Bals.) Vuillemin sobre estados inmaduros de mosquita blanca (*Bemisia tabaci* Genn.). Fitosanidad 13(2): 89- 93.

Ruiz V., J., T. Aquino B., M. E. Silva R. y S. Girón P. 2012. Control integrado de la gallina ciega *Phyllophaga vetula* Horn (Coleoptera: Melolonthidae) con agentes entomopatógenos en Oaxaca, México. Revista Científica UDO Agrícola 12 (3): 609-616.
Sánchez P., L., S. Rodríguez N., V. Marín C., M. Ramos L., A. Ramos and J. Barranco F. 2016. Assessment of Beauveria bassiana and their enzymatic extracts against Metamasius spinolae and Cyclocephala lunulata in laboratory. Advances in Enzyme Research 4: 98-112. Doi:10.4236/aer.2016.43010.

Secretaría de Agricultura, Ganadería, Desarrollo Rural, Pesca y Alimentación (Sagarpa). 2015. Modificación a la Norma Oficial Mexicana NOM-032-FITO-1995, por la que se establecen los NOM-032-FITO-1995. 2015. Requisitos y especificaciones fitosanitarias para la realización de estudios de efectividad biológica de plaguicidas agrícolas y su Dictamen Técnico. Diario Oficial de la federación. Tercera sección. Martes 11 de agosto de 2015. https://dof.gob.mx/nota_doc.php%3Fcodnota%3D5403310 (26 de enero de 2019).

Sociedad Mexicana de Control Biológico (SMCB). 2018. Página oficial de la SMCB. https://www.smcb-mx.org/. (22 de noviembre de 2018).

Solís S., A., C. García G., M. B. González M., H. Medrano R. y L. J. Galán W. 2006. Toxicidad de blastosporas de Beauveria bassiana (Vuill) sobre palomilla del manzano Cydia pomonella L. (Lepidoptera: Tortricidae). Folia Entomológica Mexicana 45(2): 195-200.

Tafoya, F., M. Zúñiga D., R. Alatorre, J. Cibrián T. and D. Stanley. 2004. Pathogenicity of Beauveria bassiana (Deuteromycota: hyphomycetes) against the cactus weevil, Metamasius spinolae (Coleoptera: Curculionidae) under laboratory conditions. Florida Entomologist 87(4): 533-536. Doi:10.1653/0015-4040(2004)087[0533:POBBDH]2.0.CO;2.

Tamayo M., F. 2009. Control biológico de Sphenarium purpurascens (Charpentier) y Melanoplus differentialis (Thomas) (Orthoptera: Acrididae) con metarhizium anisopliae (Metschnikoff) Sorokin, en Guanajuato, México. Vedalia 13 (2): 85-90.

Toledo, J., J. L. Gurgúa, P. Liedo, J. E. Ibarra y A. Oropeza. 2001. Parasitismo de larvas y pupas de la mosca mexicana de la fruta Anastrepha ludens (Loew) (Diptera: tephritidae) por el nematodo Steinernema feltiae (Filipjev) (Rhabditida: Steinernematidae). Vedalia 8: 27-36.

Toledo, J., C. Pérez, P. Liedo y J. E. Ibarra. 2005. Susceptibilidad de larvas de Anastrepha obliqua macquart (Diptera: Tephritidae) a Heterorhabditis bacteriophora (Poinar) (Rhabditida: Heterorhabditidae) en condiciones de laboratorio. Vedalia 12 (1): 11-22.
Trevor, W., H. C. Arredondo B. and L. A. Rodríguez del B. 2013. Biological pest control. Annual Review of Entomology 58:119–40. Doi: 10.1146/annurev-ento-120811-153552.

Villegas R., F., O. Díaz G., J. S. Casas F., C. T. Monreal V., F. Tamayo M. y S. Aguilar Ml. 2017. Actividad de dos hongos entomopatógenos, identificados molecularmente, sobre Bactericera cockerelli. Revista Colombiana de Entomología 43(1): 27-33. Doi:10.25100/socolen.v43i1.6643.

Zumaquero R., J. L., J. J. López T., R. Rojas G. and S. Estibaliz. 2014. Lethal effects of a Mexican Beauveria bassiana (Balsamo) strain against Meccus pallidipennis (Stal). Brazilian Journal of Microbiology 45(2): 551-557. Doi:10.1590/S1517-83822014000200025.

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