Article

# Importance of biological control of pests in corn (*Zea mays* L.)

Antonia Hernandez-Trejo[1]
Benigno Estrada Drouaillet[1]
Raúl Rodríguez-Herrera[2]
José Manual García Giron[1]
Sara Alejandra Patiño-Arellano[3]
Eduardo Osorio-Hernández[1§]

[1]Faculty of Engineering and Sciences-Autonomous University of Tamaulipas. Matamoros s/n. Downtown Victoria City, Tamaulipas. CP. 87000. (antonyya-17@hotmail.com; benestrada@docentes.uat.edu.mx; ggiron@docentes.uat.edu.mx). [2]Autonomous University of Coahuila-Faculty of Chemical Sciences. Blvd. V. Carranza and José Cárdenas s/n, Saltillo, Coahuila, Mexico. CP. 25000. (raul.rodriguez@uadec.edu.mx). [3]Postgraduate College-*Campus* Montecillo. Highway Mex-Tex km 36.5, Montecillo, Texcoco, State of Mexico. CP. 56230. (sarahlianpasa@gmail.com).

[§]Corresponding author: eosorio@docentes.uat.edu.mx.

## Abstract

Plague insects are one of the main constraints in the production of corn crops. Therefore, they cause damage to the development of the plant and therefore reduce performance. The armyworm *Spodoptera fugiperda* J. E. Smith and *Heliothis zea* (Boddie), (Lepidoptera: Noctuidae) are the most present in the cultivation of corn. For the control of these and other pests, the most used control are chemical insecticides; the main disadvantages of its use have been the contamination of the environment and the resistance of insect pests, this has caused damage to the environment and resistance. An alternative is the use of entomopathogenic microorganisms, predators or parasitoids. Within these are entomopathogenic fungi such as *Metarhizum anisopliae* (Metchnikoff) Sorokin, and predators of the family Coccinellidae as *Cycloneda sangunea* (Linnaeus), being these most used in biological control. Also, some parasitoids such as *Telenomus remus* (Nixon) (Hymenoptera: Platygastridae). Therefore, the advantages of biological control is to reduce levels of pest infestation to a proportion that do not cause economic damage, reduce the spectrum of action and also do not generate pollution to the environment. The biological control depends to a large extent on the climatic conditions, phenological stage of the crop and the interaction between the pests and the host.

**Keywords:** entomopathogen, lepidoptera, parasitoid.

Reception date: February 2019
Acceptance date: May 2019

# Introduction

The cultivation of corn (*Zea mays* L.) presents several phytosanitary problems for its production, among the main ones are weeds, diseases and plague insects (Reséndiz *et al*., 2016), the latter stand out due to the damage they cause and estimated to cause yield losses of 30%, these occur from the establishment of the crop to grain storage (Valdéz-Torres *et al*., 2012).

The incidence of insect pests and the damage they cause in crops is given by various factors such as environmental conditions, crop phenology (Ayala *et al*., 2013) and habits of the insect pest, either food or even biological characteristics (Reséndiz *et al*., 2016). On the other hand, it is reported that corn is damaged by more than 70 species of insect pests (Turrent *et al*., 2010), these have a great diversity, in terms of chlorination, shape, size or preference of various crops, the above it allows them to be differentiated (Méndez and González, 2014). In addition, depending on the damage they cause in the plant, they are classified as pests of foliage, root, ear and grain (Turrent *et al*., 2010).

On the other hand, it is important to mention that the main method of control of insect pests are chemical insecticides (Pérez-Agis *et al*., 2004; González-Maldonado *et al*., 2015). The effects of the application of chemical products on agricultural production systems have been effectively adapted, being a broad-spectrum and fast-acting strategy (Reséndiz *et al*., 2016).

The latter has favored pollution with various effects on the environment, causing the elimination of natural enemies and even intoxication to human health (Troyo-Diéguez *et al*., 2006, Santos *et al*., 2015) and in addition to causing resistance in pests; example of this last one is the one caused by carbamates and pyrethroids to *Spodoptera fugiperda* J. E. Smith (Lepidoptera: Noctuidae) (León-García *et al*., 2012). It is important to highlight that the adverse effects caused by the application of chemical insecticides are due to the irrational use with which they are used, since, the infestation levels are not considered by insect pests mainly (Cano *et al*., 2004).

For all the above, it is convenient to make some control alternatives, to reduce the use of insecticides such as physical, natural and biological control considered as efficient alternatives (Angel-Ríos *et al*., 2015). Biological control is considered a viable and safe alternative for the environment (Cano *et al*., 2004). This is based on using living organisms on insect pests (Carreras, 2011). Of these, entomopathogenic microorganisms such as bacteria are mentioned, where it is reported that *Bacillus thuringiensis* (Berliner) (González-Maldonado *et al*., 2015), which is used to a great extent for the control of insect pests, which has the characteristic of presenting an effect when ingested by the insect, this bacterium produces intestinal paralysis and prevents it from continuing to feed (Jojoa-Bravo and Salazar-González, 2011).

On the other hand, the use of entomopathogenic fungi, such as *Metarhizium anisopliae* (Metchnikoff) Sorokin (the causal agent of green muscardin), which causes loss of mobility and coordination in the insect, cessation of feeding, finally causing death (Angel-Ríos *et al*., 2015). Likewise, entomopathogenic viruses have high virulence in some insects that cause losses in corn production, especially in pests of the order Lepidoptera (Gómez *et al*., 2010).

On the other hand, parasitoids have been successful in the control of insect pests such as *Telenomus remus* Nixon (Hymenoptera: Platygastridae), which is an egg-stage parasitoid (Farhat *et al*., 2013). In the same way, predatory insects, such as catarinitas (Coleoptera: Coccinellidae), lacewings (Neuroptera: Chrysopidae) (Figure 1) and syrphids (Diptera: Syrphidae) as regulators of plague insect populations (García-Gutiérrez *et al*., 2012).


**Figure 1. *Chrysoperla carnea* associated with pest control (a) and *Cycloneda sanguinea* (b).**

## Problematic due to the application of chemical insecticides on insect pests in corn cultivation

Corn has great biological diversity, which is why it is cultivated in diverse environments (Reséndiz *et al*., 2014). Concerning its economic and cultural importance, corn is produced in large quantities, hence its great importance as a staple food in Mexico (Angel-Ríos *et al*., 2015). However, this crop is susceptible to insect pests and diseases (Ramírez-Díaz *et al*., 2015), despite the fact that chemical insecticides have a good effect on their control, since they greatly reduce population densities, many times another plague species is present (Troyo-Diéguez *et al*., 2006).

Due to this, the pests considered occasional have become primary and therefore have caused significant losses (González-Maldonado *et al*., 2015). It is estimated that for the control of the armyworm, being one of the pests with the highest incidence in the cultivation of corn, applications of chemical insecticides are made in around 4 million hectares (Blanco *et al*., 2010). Therefore, it is also estimated that about 2 600 t of chemical insecticides are destined for *S. frugiperda*, which is mentioned for the state of Sinaloa, which between 2007 and 2011, 500 000 hectares per year were established, all this gives us a panorama of the number of applications made, as well as the surface to which it is intended (Cortez-Mondaca *et al*., 2012).

This is just a panorama of the large amounts of agrochemicals used to control a proportion of different species of insect pests, so this problem has been observed with the option of giving added value when using non-conventional alternatives such as biological control, when considered as an organic crop, free of chemical products (Duarte, 2012).

## Factors that influence the growth of plague insect populations

Environmental conditions have an important influence on the population growth of pests (Reséndiz *et al*., 2016). On the other hand, it is known that climate change causes alteration in the distribution, incidence and intensity of pests (Grageda *et al*., 2014), therefore it is considered important to predict the relationship between the phenological stage of the culture and the plague (Méndez and González, 2014). On the other hand, a factor that intervenes in the presence and abundance so that the plague insect has presence with the monoculture sowings (Cortez-Mondaca *et al*., 2012).

In addition, when indiscriminate chemical applications are made, they cause resistant organisms and their reproduction is increased (Murguido and Elizondo, 2007). Prediction models are used as a forecast, to then carry out an optimal control method; taking into account the relationship between the presence of the pest, crop phenology and temperature as an important factor (Valdez-Torres *et al*., 2012).

**Main pests of corn**

More than 80 species or complexes of pests species are considered in the corn crop and around 50 pests considered as occasional (Table 1) (Fernández, 2002). On the other hand, *S. frugiperda* (Figure 2) is considered the most important pest insect in corn cultivation (Rangel *et al*., 2014). This insect feeds on the first vegetative stages (bud and tender leaves) until it is completely defoliated (Valdez-Torres *et al*., 2012). This plague is present all year round, so it additionally attacks stem and ear, competing with the elder worm *Helicoverpa zea* Boddie (Lepidoptera: Noctuidae) (González-Maldonado *et al*., 2015). On the other hand, the soldier worm *Spodoptera exigua* Hübner (Lepidoptera: Noctuidae) is a pest that attacks the leaf and ear of corn, has a complete life cycle, develops between 15-25 days, then goes through five larval stages (García-Gutiérrez *et al*., 2012; González-Maldonado *et al*., 2015).

**Table 1. Potential insect pests in corn.**

| Plague | Phenological stage | Biological state (damage) | Biologic control | Author |
|---|---|---|---|---|
| Warbler worm *S. frugiperda* | All the phenological stage | Larvae | C*helonus insularis*, *T. remus* y *M. anisopliae* | Lugo-García *et al*. (2012); González-Maldonado *et al.* (2015); Ordóñez-García *et al*. (2015); Lezema *et al*. (2005) |
| Thread worm *Agrotis ípsilon* | Germination, vegetative development | Larvae | *B. thuringiensis* | Jojoa-Bravo and Salazar-González (2011); García-Gutiérrez *et al*. (2012) |
| Worm eloter *H. zea* | Flowering, ripening | Larvae | *Trichogramma* sp. | García-Gutiérrez *et al*. (2012) |
| Stigmata fly *E. stigmatias* | Maturation | Adult | *Orius insidiosus* y *Spalangia* spp. | Camacho-Báez *et al*. (2012); Farhat *et al*. (2013) |
| Soldier worm *S. exigua* | Germination, vegetative development | Larvae | *B. thuringiensis*, *Telenomus* sp. y *Heterorhbditis bacteriophora* | Vázquez *et al*. (2010); García-Gutiérrez *et al*. (2012) |

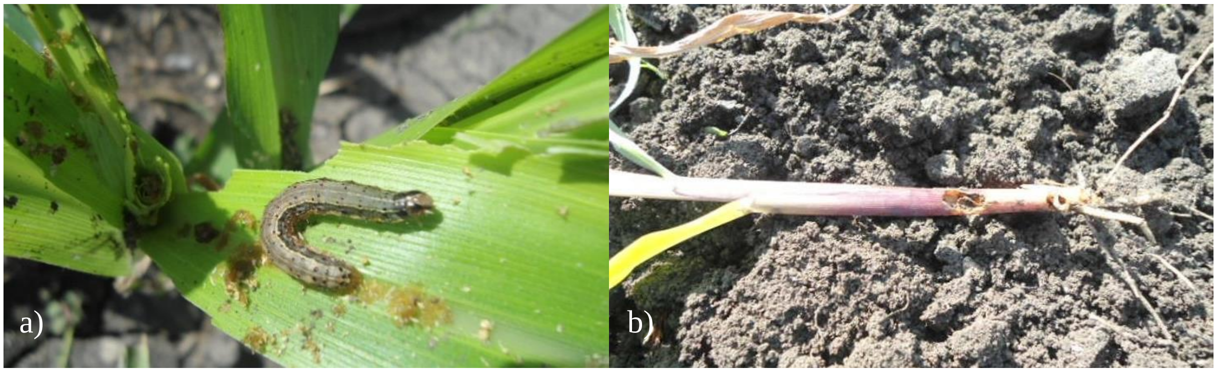


**Figure 2. Damage by warbler worm (a) and damage by braid worm (b).**

Another plague that harms corn, especially the root zone is the blind chicken *Phyllophaga* spp. (Coleoptera: Melolonthidae), the damage causes it in the larval stage, causing the germination to be lost and rickets develop, its biological cycle lasts around 1 or 2 years going through different stages (Lugo-García *et al*., 2012). Another of the rhizophagous pests of corn known as Diabrotica or braid worm *Diabrotica virgifera* zeae Krysan and Smith (Coleoptera: Chrysomelidae) (Figure 2), causes damage in the development of the crop by feeding on the roots, has several stages and its biological cycle is of around 45 days (Pérez *et al*., 2006).

On the other hand, *Helicoverpa zea* Boddie (Lepidoptera: Noctuidae) is a polyphagous species that affects various crops, the damage is caused by larvae in corn and ear grains, the larval stage is 16 days, it has cannibalistic habits and it also favors the appearance of other pests (García-Gutiérrez *et al*., 2012), such as the stigma fly *Euxesta stigmatias* Loew (Diptera, Otitidae= Ulidiidae), which causes decay that affects corn quality and grain yield, the damage causes it Larva status, it is estimated that around 70% are lost, in cycles with favorable conditions (Camacho-Báez *et al*., 2012).

## Biological control of insect pests

Particularly, biological control is a viable alternative, contributes to sustainability and does not affect the environment (Hernández-Velázquez *et al*., 2011). The interest that has been observed regarding the use of biological control agents is due to the demand of these, since centers of reproduction of beneficial organisms have been created (Salas-Araiza and Salazar-Solis, 2003). Therefore, insects' parasitoids, predators and pathogenic microorganisms (Rios *et al*., 2017), are used with the purpose of decreasing pest insect populations at a level that does not cause economic damage (Vázquez-Ramírez *et al*., 2015).

Parasitoids are considered insects with a wider activity, due to their diverse search capacity, which gives them the ability to reproduce and thus give continuity to the species (Salas-Araiza and Salazar-Solis, 2003). On the other hand, the predators are a group of organisms that consume different plague insects and considered as generalists, of these they emphasize the catarinas in their diverse colors like those of the family Coccinellidae; they are used for the control of Lepidoptera eggs (Hernández-Trejo *et al*., 2018). In addition, entomopathogenic microorganisms such as bacteria, viruses and fungi are widely used (Vázquez-Ramírez *et al*., 2015). So that they do not present a risk to the environment or harmful effects on human health; in addition, they have adequate control and strengthen the practices of integrated pest management (Rios *et al*., 2017).

It is clear that the intention exercised by the use of biological control in the population of pests, has as its primary focus complemented not replace (Gallegos *et al*., 2003; Murguido and Elizondo, 2007). Besides reducing risks of resistance and the amount of chemical applications in crops (Carreras, 2011). So, it is evident the results that the release of egg parasitoids from pest insects has shown in the field (Figure 3), and where it has caused more than 80% mortality on the egg stage of *S. frugiperda* (Farhat *et al*., 2013).

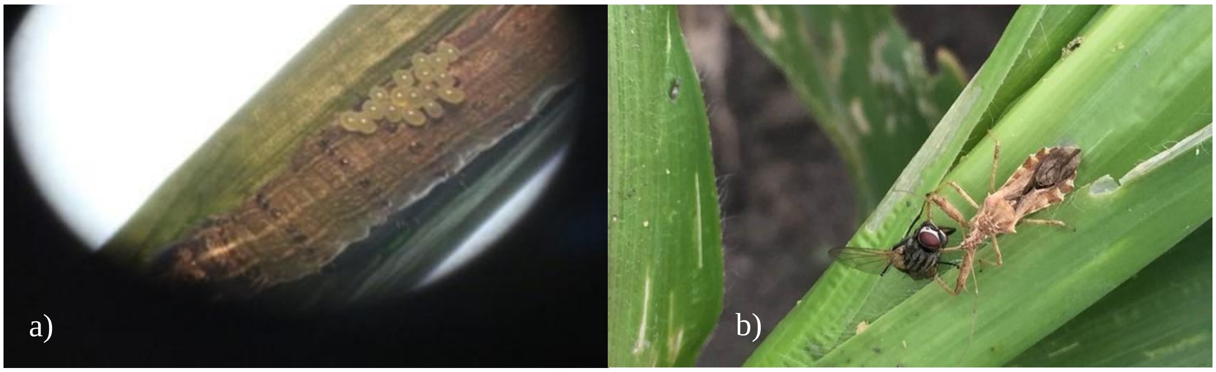


**Figure 3. Parasitoid eggs on *S. frugiperda* (a) and depredation of flies by chiche (b).**

## Entomopathogens for the control of pests in corn

The entomopathogenic fungi are microorganisms that have the particularity to parasitize different groups of insects and even some arthropods; the biological cycle of these comprises two phases: the first parasitic and the second saprophyte (Schapovaloff *et al*., 2015). Some of these, such as *M. anisopliae* which is considered one of the main entomopathogenic fungi that control some pests of Lepidoptera of agricultural importance (Acuña *et al*., 2015) and mainly feed on larval stages (Del Rincón-Castro *et al*., 2006).

It is known that there are different groups of entomopathogenic fungi with more than 750 species, which are found in the environment (Motta-Delgado and Murcia-Ordoñez, 2011), in addition to the soil that also constitutes a reservoir for different fungi and that contribute to the regulation of pest insect populations (Schapovaloff *et al*., 2015). The genera considered to be the most important are: *Metarhizium*, *Beauveria*, *Aschersonia*, *Entomophthora*, *Fusarium*, *Hirsutella*, *Paecelomyces* and *Verticillium*, among others (Motta-Delgado and Murcia-Ordoñez, 2011).

In Mexico, several studies have confirmed the presence of entomopathogenic fungi such as *M. anisopliae*, *Beauveria bassiana* (Bals.) Vuill and *Paecilomyces* sp., in corn crops (Hernández-Velázquez *et al*., 2011). Regarding the biological control that is exerted on some plague insects, the entomopathogenic fungi *Metarhizium* and *Paecilomyces* have been used on larvae of *S. frugiperda* (Ángel-Ríos *et al*., 2015). Also, *B. bassiana* is known for its wide range of hosts, develops a white mycelium that covers the insect after being infected and has been evaluated on larvae of *Galleria mellonella* (Gallegos *et al*., 2003). *Isaria fumosoroseus* (formerly known as *Paecilomyces fumosoroseus*) is found to affect insect pests and has been considered as a potential control agent because it does not affect other beneficial insects (Flores *et al*., 2013).

These pathogenic microorganisms are effective in the control of insect pests (Rios *et al*., 2017), however, It is important to emphasize that this requires the development of the conditions required for their reproduction, in addition to considering the management that has been given in the preparation until the application thereof (Motta-Delgado and Murcia-Ordoñez, 2011; Ángel-Ríos *et al*., 2015). For all the above, it is important to mention that these microorganisms are the most used for the control of insect pests (Rios *et al*., 2017).

Entomopathogenic viruses are another group of organisms that cause epizootics on insect pests and viral infection occurs orally, through the ingestion of food contaminated with viral occlusion bodies (Cano *et al*., 2004). It is reported that at least 12 families of viruses infect insects and some arthropods, being those of the family Baculoviridae the most studied, these affect larvae of insect pests such as *S. frugiperda* (Rios *et al*., 2017).

Among the microorganisms of bacteria, the most important is *Bacillus thuringiensis*, which has a selective toxicity because it has a broad spectrum, especially a specificity for lepidopteran insects (Sauka and Benintende, 2008). It is used for the control of the *Agrotis ipsilon* (Hufnagel) (Lepidoptera: Noctuidae) (Jojoa-Bravo and Salazar-González, 2011). Therefore, the biological control based on entomopathogenic microorganisms in the combat of insect pests is promising, because they cause mortality in different biological stages (Lezama *et al*., 2007).

**Natural enemies for the control of pests in corn**

Natural enemies are an important part of pest insect regulation and occur naturally in corn crops, both predators and parasitoids (Hernández-Trejo *et al*., 2018). Due to the diversity of natural enemies, habits, life cycle, metabolism, among others, each one of the pests could be controlled by different predators or parasitoids, being some specific (Hernández-Velázquez *et al*., 2012).

Within the great diversity of insects that affect corn is the stigma fly (*Euxesta stigmatias*) (Figure 3) and is parasitized by several species such as some wasps of the genus *Spalangia* (Hymenoptera: Pteromalidae) specifically in stage of pupae, this fly is introduced and deposits its eggs inside this (Camacho-Báez *et al*., 2012). For the case of *S. frugiperda*, it is parasitized by several species such as *Chelonus insulares* Cresson and by *Meteorus* sp., (Nees) (Rios *et al*., 2017) and also the Ichneumonidae family, highlighting the species *Campoletis sonorensis* (Cameron), also wasps such as some species of the genus *Trichogramma* are the parasitoids most used in the biological control of lepidoptera (Hernández-Trejo *et al*., 2018). In addition to this, programs have been designed through the release of parasitoids, such as *Telenomus remus*, for the biological control of *S. frugiperda*, with satisfactory results (Farhat *et al*., 2013). On the other hand, for the control of *H. zea*, the parasitoid *Cotesia marginiventris* Cresson, (Hymenoptera: Braconidae) has been reported (García-Gutiérrez *et al*., 2012).

The predators are considered polyphagous insects, so they are less specific than the parasitoids, of these the hemimetabolos stands out, the order Hemiptera is one of the most effective, standing out the family Pentatomidae, Lygaeidae, Nabidae, Miridae, among others (Rios *et al*., 2017). An example of these is the pirate bug (*Orius insidiosus*) (Say) (Hemiptera: Anthocoridae) which is a predator of the stigma fly in different biological states and so it is considered promising to be used as a biological control agent, besides that it has been observed that it feeds on lepidopteran eggs; the murine bug *Sinea* sp., (Hemiptera: Reduviidae) that preys on *S. frugiperda* larvae (Camacho-Báez *et al*., 2012).

Likewise, holometabolos stand out in the order Diptera, Coleoptera, Neuroptera, and Hymenoptera (Rios *et al*., 2017), as an example, this *Trichogramma* sp., (Hymenoptera: Trichogrammatidae) as natural enemies of lepidoptera. Therefore, predators considered generalists, continue to play an important role, since in various biological states of corn cultivation (García-Gutiérrez *et al*., 2012).

## Conclusions

Corn is affected by a wide variety of insect pests, there are primary and secondary pests, all present in different vegetative stages, causing damage in minor and greater proportion. There is a great diversity and abundance of parasitoids, predators and entomopathogenic microorganisms, in contrast to the above it will depend on the insect to fight and the conditions in which one wants to exercise biological control, which can be considered as part of a program of biologic control.

Reason why it is necessary to consider a less aggressive control with the environment as biological control, being a feasible alternative that contributes to the sustainability that also seeks to reduce the number of chemical applications. However, biological control is not entirely acceptable, due to the time required to perform its action, which is longer compared to chemicals. However, despite this, organic agriculture has been considered, due to the demand for products without chemical applications.

## Cited literature

Acuña, J. M.; García, G. C; Rosas, G. N. M.; López, M. M. y Saínz, H. J. C. 2015. Formulación de *Metarhizium anisopliae* (Metschnikoff) Sorokin con polímeros biodegradables y su virulencia contra *Heliothis virescens* (Fabricius). Rev. Inter. Contam. Amb. 31(3):219-226.

Ángel-Ríos, M. D.; Pérez-Salgado, J. y Morales, F. J. 2015. Toxicidad de extractos vegetales y hongos entomopatógenos en el gusano cogollero *Spodoptera frugiperda* J.E. Smith (Lepidoptera: Noctuidae), del maíz en el estado de Guerrero. Entomol. Mex. 2:260-265.

Ayala, R. O.; Navarro, F. and Virla, E. G. 2013. Evaluation of the attack rates and level of damages by the fall armyworm, *Spodoptera frugiperda* (Lepidoptera: Noctuidae), affecting corn-crops in the northeast of Argentina. Rev. Fac. Cienc. Agr. 45(2):1-12.

Blanco, C. A.; Portilla, M.; Jurat-Fuentes, J. L.; Sánchez, J. F.; Viteri, D.; Vega-Aquino, P.; Terán-Vargas, A. P.; Azuara-Domínguez, A.; López, J. D.; Arias, R.; Yu-Cheng, Z.; Lugo-Barrera, D. and Jackson, R. 2010. Susceptibility of isofamilies of *Spodoptera frugiperda* (Lepidoptera: Noctuidae) to Cry1Ac and Cry1Fa proteins of *Bacillus thuringiensis.* Southwestern Entomol. 35(3):409-415.

Camacho-Báez, J. R.; García-Gutiérrez, C.; Mundo-Ocampo, M.; Armenta-Bojorquez, A. D.; Nava-Pérez, E.; Valenzuela-Hernández, J. I. y González-Guitrón, U. 2012. Enemigos naturales de las moscas de los estigmas del maíz: *Euxesta stigmatias* (Loew), *Chaetopsis massyla* (Walker) y *Eumecosommyia nubila* (Wiedemann) en Guasave Sinaloa, México. Ra Ximhai. 8(3b):71-77.

Cano, E.; Carballo, M.; Chaput, P.; Fernández, O.; González, L.; Grueber, A. K., Guharay, F.; Hidalgo, E.; Narváez, C.; López, P. J. A.; Rizo, C.; Rodríguez, A.; Rodríguez, C. y Salazar, D. 2004. Control biológico de plagas agrícolas. INPASA. Managua. 232 p.

Carreras, S. B. 2011. Aplicaciones de la bacteria entomopatógena *Bacillus thuringiensis* en el control de fitopatógenos. Corpoica. Ciencia y Tecnología Agropecuaria. 12(2):129-133.

Cortez-Mondaca, E.; Pérez-Márquez, J. y Bahena-Juárez, F. 2012. Control biológico natural de gusano cogollero (Lepidoptera: Noctuidae) en maíz y en sorgo, en el norte de Sinaloa, México. Southwestern Entomologist Scientific Note. 37(3):423-428.

Del Rincón-Castro, M. C.; Méndez-Lozano, J. e Ibarra, J. E. 2006. Caracterización de cepas nativas de *Bacillus thuringiensis* con actividad insecticida hacia el gusano cogollero del maíz *Spodoptera frugiperda* (Lepidoptera: Noctuidae). Folia Entomol. Mex. 45(2):157-164.

Duarte, C. F. 2012. El control biológico como estrategia para apoyar las exportaciones agrícolas no tradicionales en Perú: un análisis empírico. Contabilidad y Negocios. 14(7):81-100.

Farhat, P. A.; De Freitas, B. A.; Oliveira, F. B. R. C.; De Oliveiras, M. J. A. y Prado, F. F. A. C. 2013. Releasing number of *Telenomus remus* (Nixon) (Hymenoptera: Platygastridae) against *Spodoptera frugiperda* Smith (Lepidoptera: Noctuidae) in corn, cotton and soybean. Ciencia Rural. 43(3):377-382.

Fernández, J. L. 2002. Nota corta: estimación de umbrales económicos para *Spodoptera frugiperda* (J.E. Smith) (Lepidoptera: Noctuidae) en el cultivo del maíz. Inv. Agron. 17(3):467-474.

Flores, M. F.; Pucheta, D. M.; Ramos-López, M. R.; Rodríguez, N. S.; Ramos, E. G. y Juárez, R. D. 2013. Estudio del hongo entomopatógeno *Isaria fumosorosea* como control microbiológico de la mosquita blanca *Bemicia tabaci*. Interciencia. 38(7):523-527.

Gallegos, M. G.; Cepeda, S. M. y Olayo, P. R. P. 2003. Entomopatógenos. Trillas, México, DF. 148 p.

García-Gutiérrez, C.; González-Maldonado, M. B. y Cortez-Mondaca, E. 2012. Uso de enemigos naturales y biorracionales para el control de plagas de maíz. Ra Ximhai. 8(3b):57-70.

Gómez, V. J. A.; Guevara, A. E. J.; Barrera C. G. P.; Cotes, P. A. M. y Villarreal, R. L. F. 2010. Aislamiento, identificación y caracterización de nucleopoliedrovirus nativos de *Spodoptera frugiperda* en Colombia. Rev. Fac. Nac. Agron. 63(2):5511-25520.

González-Maldonado, M. B.; Gurrola-Reyes, J. N. y Chaírez-Hernández, I. 2015. Productos biológicos para el control de *Spodoptera frugiperda* (Lepidoptera: Noctuidae). Rev. Colomb. Entomol. 41(2):200-204.

Grageda, G. J.; Ruiz, C. J. A.; Jiménez, L. A. y Fu, C. A. A. 2014. Influencia del cambio climático en el desarrollo de plagas y enfermedades de cultivos en Sonora. Rev. Mex. Cienc. Agríc. 10:1913-1921.

Hernández-Trejo, A.; Osorio-Hernández, E.; López-Santillán, J. A.; Ríos-Velasco, C.; Varela-Fuentes, S. E. y Rodríguez-Herrera, R. 2018. Insectos benéficos asociados al control del gusano cogollero (*Spodoptera frugiperda*) en el cultivo de maíz (*Zea mays* L.). Agroproductividad. 11(1):9-14.

Hernández-Velázquez, V. M.; Cervantes, E. Z.; Villalobos, F. J.; Lina G. L. y Peña, C. G. 2011. Aislamiento de hongos entomopatógenos en suelo y sobre gallinas ciegas (Coleoptera: Melolonthidae) en agroecosistemas de maíz. Acta Zoológica Mexicana (nueva serie). 27(3):591-599.

Jojoa-Bravo, C. J. y Salazar-González, C. 2011. Evaluación *in vitro* de insecticidas biorracionales para el control de *Agrotis ipsilon* Hüfnagel. Rev. Cienc. Agríc. 28(1):53-63.

León-García, I.; Rodríguez-Leyva, E.; Ortega-Arenas, L. D. y Solís-Aguilar, J. F. 2012. Susceptibilidad de *Spodoptera frugiperda* (J.E. Smith) (Lepidoptera: Noctuidae) a insecticidas asociada a césped en Quintana Roo, México. Agrociencia. 46(3):279-287.

Lezama, R.; Molina, J.; López, M.; Pescador, A.; Galindo, E.; Ángel, C. A. y Michel, C. A. 2005. Efecto del hongo entomopatógeno *Metarhizium anisopliae* sobre el control del gusano cogollero del maíz en campo. Av. Inves. Agrop. 9(1):069-074.

Lugo-García, G. A.; Ortega-Arena, L. D.; Aragón-García, A.; González-Hernández, H.; Romero-Nápoles, J.; Reyes-Olivas, A. y Morón, M. A. 2012. Especies de gallina ciega (Coleoptera: Scarabaeoidea) asociadas al cultivo de maíz en Ahome, Sinaloa, México. Agrociencia. 46(3):307-320.

Méndez, B. A. y González, P. Y. M. 2014. Plagas asociadas al cultivo del maíz (*Zea mays* L.) en un área del estado Aragua, Venezuela. Fitosanidad. 18(3):175-179.

Motta-Delgado, P. A. y Murcia-Ordoñez, B. 2011. Hongos entomopatógenos como alternativa para el control biológico de plagas. Revista Ambiente e Agua 6:77-90.

Murguido, M. C. A. y Elizondo, S. A. I. 2007. El manejo integrado de plagas de insectos en Cuba. Fitosanidad. 11(3):23-28.

Ordóñez-García, M.; Bustillos-Rodríguez, J. C.; Loya-Márquez, J.; Ríos-Velasco, C. y Jacobo-Cuellar, J. L. 2015. Parasitoides de *Spodoptera frugiperda* (J.E. Smith) (Lepidoptera: Noctuidae) en Chihuahua, México. Métodos en Ecología y Sistemática. 10(1):67-72.

Pérez, D. J. F.; Romero R. F.; Soltero, D. L. y Álvarez, Z. R. 2006. Susceptibilidad en híbridos de maíz a diabrótica (*Diabrotica virgifera* zeae) en México. Agric. Téc. Méx. 32(2):143-151.

Pérez-Agis, E.; Vázquez-García, M.; González-Eguiarte, D.; Pimienta-Barrios, E.; Nájera-Rincón, M. B. y Torres-Morán, P. 2004. Sistemas de producción de maíz y población de macrofauna edáfica. Terra Latinoam. 22(3):335-341.

Ramírez-Díaz, J. L.; Ledesma-Miramontes, A.; Vidal-Martínez, V. A.; Gómez-Montiel, N. O.; Ruiz-Corral, J. A.; Velázquez-Cardelas, G. A.; Ron-Parra, J.; Salinas-Moreno, Y. y Nájera-Calvo, L. A. 2015. Selección de maíces nativos como donadores de características agronómicas útiles en híbridos comerciales. Rev. Fitotec. Mex. 38(2):119-131.

Rangel, N. J. C.; Vázquez R. M. F. y Del Rincón, C. M. C. 2014. Caracterización biológica y molecular de cepas exóticas de baculovirus SfNPV, con actividad bioinsecticida hacia una población mexicana del gusano cogollero del maíz *Spodoptera frugiperda* (Lepidóptera: Noctuidae). Interciencia. 39(5):320-326.

Reséndiz, R. Z.; López S. J. A., Briones, E. F.; Mendoza, C. M. C. y Varela, F. S. E. 2014. Situación actual de los sistemas de producción de grano de maíz en Tamaulipas, México. Investigación y Ciencia. 22(62):69-75.

Reséndiz, R. Z.; López, S. J. A.; Osorio, H. E.; Estrada D. B., Pecina, M. J. A.; Mendoza, C. M. C. y Reyes, M. C. A. 2016. Importancia de la resistencia del maíz nativo al ataque de larvas de lepidópteros. Temas de Ciencia y Tecnología. 20(59):3-14.

Rios, V. C.; Bustillos, R. J. C.; Ordoñez, G. M.; Ruiz, C. M. F.; Berlanga, R. D. I.; Ornelas, P. J. J.; Zamudio, F. P. B.; Acosta, M. C. H.; Olivas, O. G. I.; Sepúlveda, A. D. R.; Salas, M. M. A.; Jacobo, C. J. L.; Cambero, C. O. J. y Gallegos, M. G. 2017. Manual de uso y aplicación de bioinsecticidas microencapsulados para el manejo de *Spodoptera frugiperda* y *Helicoverpa zea.* Centro de Investigación en Alimentos y Desarrollo, A.C. Unidad Cuauhtémoc 56 p.

Salas-Araiza, M. D. y Salazar-Solís, E. 2003. Importancia del uso adecuado de agentes de control biológico. Acta Universitaria. 13(1):29-35.

Santos, C. G. D.; Wanderley, T. V.; Vargas, de O. J.; Aguiar, C. T. A.; Correia, A. A.; de Souza, A. T. J.; Magliano, da C. F. and Oliveira, B. M. 2015. Histological and histochemical changes by clove essential oil upon the gonads of *Spodoptera frugiperda* (JE Smith) (Lepidoptera: Noctuidae). Inter. J. Morphol. 33(4):1393-1400.

Sauka, D. H. y Benintende, G. B. 2008. *Bacillus thuringiensis*: generalidades. Un acercamiento a su empleo en el biocontrol de insectos lepidópteros que son plagas agrícolas. Rev. Argentina Microbiol. 40(2):124-140.

Schapovalo, M. E.; Angeli, A. L. F.; Urrutiac, M. I. y López, L. C. C. 2015. Ocurrencia natural de hongos entomopatógenos en suelos cultivados con yerba mate (*Ilex paraguariensis* St. Hil.) en Misiones, Argentina. Rev. Argentina Microbiol. 47(2):138-142.

Troyo-Diéguez, E.; Servín-Villegas, R.; Loya-Ramírez, J. G.; García-Hernández, J. L.; Murillo-Amador, B.; Nieto-Garibay, A.; Beltrán, A.; Fenech, L. y Arnaud-Franco, G. 2006. Planeación y organización del muestreo y manejo integrado de plagas en agroecosistemas con un enfoque de agricultura sostenible. Universidad y Ciencia. 22(2):191-203.

Turrent, F. A.; Cortes, F. J. I.; Espinosa, C. A.; Mejía, A. H. y Serratos, H. J. A. ¿Es ventajosa para México la tecnología actual de maíz transgénico? 2010. Rev. Mex. Cienc. Agríc. 1(4):613-646.

Valdez-Torres, J. B.; Soto-Landeros, F.; Osuna-Enciso, T. y Báez-Sañudo, A. M. 2010. Modelos de predicción fenológica para maíz blanco (*Zea mays* L.) y gusano cogollero (*Spodoptera frugiperda* J. E. Smith). Agrociencia. 46(2):399-410.

Vásquez, J.; Zeddam, J. L. y Tresierra, A. A. 2002. Control biológico del "cogollero del maíz" *Spodoptera frugiperda* (Lepidoptera: Noctuidae) con el baculovirus SFVPN, en Iquitos-Perú. Folia Amazónica. 13(1-2):25-39.

Vázquez, M. L. L.; Caballero, F. S.; Carr, P. A.; Gil, M. J.; Armas, G. J. L.; Rodríguez, F. A.; Becerra, B. M.; Rodríguez, R. L. A.; Granda, S. R.; Corona, S. T.; Fumero, M. M.; Peña, R. M.; Essen, C. I.; Leyva, C. L.; Concepción, P. E.; Ramos, T. T. y Corbea, S. O. 2010. Diagnóstico de la utilización de entomófagos y entomopatógenos para el control biológico de insectos por los agricultores en cuba. Fitosanidad. 14(3):159-169.