SCIENTIAFUNGORUM

DOI: 10.33885/sf.2024.55.1450
(2024) Vol. 55: e1450

Agricultural Fungi-based Insecticides in Mexico

Insecticidas agrícolas a base de hongos en México

Karla Tatiana Murillo-Alonso [1,2], Carolina Brunner-Mendoza [2], Miguel Angel Ayala-Zermeño [3], Jhony Navat Enríquez Vara [4], Conchita Toriello [2]

[1] Laboratorio de Investigación y Desarrollo, LABTECSUS, S.A. de C.V., Jiutepec, Morelos, México.
[2] Laboratorio de Micología Básica, Departamento de Microbiología y Parasitología, Facultad de Medicina, Universidad Nacional Autónoma de México. Circuito Interior S/N, C.P. 04510, Coyoacán, Ciudad de México, México. 3 Departamento de Control Biológico, CNRF-DGSV-SENASICA-SADER. Km 1.5 Carretera Tecomán-Estación FFCC, Col. Tepeyac C.P. 28110, Tecomán, Colima, México. 4 CONACYT-Centro de Investigación y Asistencia en Tecnología y Diseño del Estado de Jalisco, A.C., CIATEJ. Camino Arenero 1227, El Bajío del Arenal, C.P. 45019 Zapopan, Jalisco, México.

RESUMEN

Antecedentes: El control de plagas agrícolas es realizado con insecticidas químicos a pesar de su impacto en la salud humana, el daño a insectos no blanco y a su persistencia ambiental. El control biológico con insecticidas agrícolas basados en hongos (AFI) ha surgido como una alternativa de bajo impacto ambiental y a la salud humana.

Objetivo: Realizar una revisión exhaustiva de la diversidad de AFI disponibles en México, con un enfoque en las especies de hongos entomopatógenos más utilizados, tipos de formulaciones, plagas que controla y su uso en campañas fitosanitarias en el país.

Métodos: Se realizó una búsqueda de AFI cuyo ingrediente activo fueran hongos entomopatógenos (EF) en directorios de laboratorios productores y comercializadores de agentes de control biológico y en sitios web de compañías comercializadoras de bioinsecticidas.

Resultados y conclusiones: Siete especies de EF como ingredientes activos en 76 productos fueron registradas, siendo *Beauveria bassiana* y *Metarhizium anisopliae* las más utilizadas en formulaciones en polvo humectable (WP). La disponibilidad de AFI brinda una alternativa al uso indiscriminado de insecticidas químicos. Los datos muestran el interés y la demanda de AFI para la agricultura mexicana y su relevancia para el control, regulación y distribución en los campos agrícolas.

Palabras clave: hongos entomopatógenos, bioinsecticidas, manejo agroecológico de plagas

ABSTRACT

Background: The control of agricultural pests is carried out with chemical insecticides despite their impact on human health, damage to non-target insects, and their environmental persistence. Biological control with Agricultural Fungi-based Insecticides (AFI) has emerged as a low-impact alternative for the environment and human health.

Objective: An exhaustive review of the diversity of AFI available in Mexico was performed, focusing on the most commonly used species of entomopathogenic fungi, types of formulations, control pests, and their use in phytosanitary campaigns in the country.

Methods: A search was conducted for AFI whose active ingredient is entomopathogenic fungi (EF) in directories of laboratories that produce and market biological control agents and on websites of companies that market bioinsecticides.

Results and conclusions: Seven species of EF were recorded as active ingredients in 76 products, with *Beauveria bassiana* and *Metarhizium anisopliae* being the most commonly used in wettable powder (WP) formulations. The availability of AFI provides an alternative to the indiscriminate use of chemical insecticides. The data show the interest and demand for AFI in Mexican agriculture and their relevance for control, regulation, and distribution in agricultural fields.

Keywords: Entomopathogenic fungi, bioinsecticides, agroecological pest management

ARTICLE HISTORY

Received 13 October 2023 Accepted 28 May 2024
On line 17 June 2024

CORRESPONDING AUTHOR

✉ Conchita Toriello, email: toriello@unam.mx
Orcid: 0000-0003-2082-9388

INTRODUCTION

Most agricultural production systems worldwide employ chemical insecticides to control pests. The global pesticide consumption in 2019 was approximately 4.19 million metric tons (Pathak *et al.* 2022). In Mexico, the average annual use of pesticides from 2010 to 2014 was 7.87 kg/ha, ranking third worldwide and first in Latin America (Zhang 2018), this has had significant consequences for the environment, public health, and the development of insect resistance (Herrera-Moreno *et al.* 2018, Li *et al.* 2023). Biological control has been developed as an environmentally friendly alternative to chemical pest control methods. It involves the introduction or enhancement of natural enemies of the pest, these can include insects, mites, nematodes, fungi, bacteria, and viruses. Specifically referring to microorganisms to enhance crop growth, increase yield, and protect crops from pathogens and pests; the global agricultural microbial market is valued at USD 6.4 billion in 2022 since the consumer preference for organic food products, gradual phase-out of crucial ingredients, residue levels in food, pest resurgence, and resistance, and increasing need for agricultural sustainability (Markets & Markets 2023).

Currently the use of Agricultural Fungi-based Insecticides (AFI) is part of the biological control strategies in integrated pest management and agroecological pest management. Unlike chemical insecticides, AFI only reduces insect populations to a level that does not cause economic losses; their toxicity is categorized as reduced or null in humans and other organisms, and due to their co-evolutionary process, they have the advantage of behaving as endophytic microorganisms that function as growth promoters and also protect plant hosts from pathogens and herbivores (Behie *et al.* 2015, Butt *et al.* 2016, Vega 2018).

AFI have increased in popularity in the last two decades with a record of 110 commercial products based on Entomopathogenic Fungi (EF), of which 40 % have *Beauveria bassiana* and 39 % *Metarhizium anisopliae* sensu lato (Faria an& Wright 2007, Mascarin & Jaronski 2016).

Since *B. bassiana* interaction with silkworms was observed by Agostino Bassi in 1835, and *M. anisopliae* studied by Eli Metchnikoff in 1878, the EF have been studied to develop microbial pest control agents (Lacey *et al.* 2015). These discoveries have promoted the study, use, and marketing of these and other EF worldwide in the 21th century.

The effectiveness of EF in agricultural pest control is attributed to their host range and sophisticated infection mechanisms. The infection process begins when susceptible insects come into contact with fungal conidia or blastospores, which then adhere to the insect cuticle. This triggers the expression of various hydrolytic enzymes, including proteases, chitinases, and lipases, as well as other factors that facilitate fungal germination and growth across the host's surface, leading to the penetration of the cuticular layers. Upon breaching the cuticle, the fungus enters the hemocoel, where host immune responses such as melanization, sclerotization, phagocytosis, nodulation, and encapsulation take place (Ortiz-Urquiza *et al.* 2013). Within the hemocoel, blastospores proliferate, invading other tissues, absorbing nutrients, and producing secondary metabolites. Ultimately, the fungus forms sporulation structures that emerge from the insect cadaver, thus continuing its life cycle (Butt *et al.* 2016).

Among the most commonly and effectively used biopesticides are the AFI whose active ingredients are entomopathogenic fungi (EF) and are used mainly as microbial insecticides against agricultural pests, as well as insect vectors of human diseases (Murillo-Alonso *et al.* 2019, Ortiz and Sansinenea 2023).

In Mexico, the Centro Nacional de Referencia de Control Biológico (CNRCB) maintains the largest collection of EF strains, which are crucial for developing biological pest control strategies, primarily in the agricultural sector. These strains encompass a variety of genera, including *Metarhizium, Beauveria, Cordyceps, Hirsutella, Simplicillium, Aschersonia, Purpureocillium, Entomophthora, Akanthomyces*, and *Gibellula* (Montesinos-Matías *et al.* 2020).

Metarhizium spp.

Metarhizium (Clavicipitaceae) is one of the most used EF worldwide. The species belonging to *Metarhizium* show a wide variety of morphological features. Conidiophores are branched but are occasionally simple in some species, with apices of branches bearing one to several phialides that may be truncate or elongate. Conidia varies in shape (cylindrical, globose, ellipsoidal) and size (from 4.0–14.5 × 2.0–5.0 µm) and may be hyaline, lilac, brown or green, and form chains

(Kepler *et al.* 2014). Although conidia are usually the only informative morphological features, these can be indistinguishable between closely related species (Brunner-Mendoza *et al.* 2018). According to the Index Fungorum and Mycobank the genus *Metarhizium* presents 111 and 123 taxon name records, respectively. This genus was initially classified into three species and varieties, but according to recent taxonomic revisions, it includes 66 species (anamorphs and teleomorphs), including those previously identified as *Metacordyceps* and *Nomuraea*, and new species have been described or incorporated to the genus (Kepler *et al.* 2014, Mongkolsamrit *et al.* 2020). Three species stand out for the control of several pests in Mexico, *M. anisopliae*, to control *Phyllophaga, Diatraea saccharalis, Aeneolamia* spp, among others (López-Rodríguez *et al.* 2023), *M. rileyi* (formerly *Nomuraea rileyi*) to control Lepidoptera and Hemiptera, and finally, *M. acridum* to control locusts (Brunner-Mendoza *et al.* 2018).

***Beauveria* spp.**

Beauveria (Cordycipitaceae) is a cosmopolitan genus of soilborne arthropod-pathogenic fungi that includes ecologically and economically important species such as *B. bassiana* characterized by white, later yellowish, or occasionally reddish colonies. The reverse is uncolored, or yellowish to pinkish. Conidiogenous cells consist of globose to flask-shaped basal part and an up to 20-mm long rachis, mostly forming a zig-zag. Conidia are hyaline, globose to broadly ellipsoidal, generally 2-3 x 2-2.5 mm. The conidia are formed in clusters, like snowballs or cotton balls (Zimmermann 2007). Currently, *Beauveria* has 81 and 88 taxon name records according to the Index Fungorum and Mycobank, respectively, and according to Rehner *et al.* (2011) *B. bassiana* and *B. brogniartii* are considered species complexes, and in recent years many species have been described or incorporated to the genus. *B. bassiana* is reported as the most potent biological control agent against a wide range of insect families (López-Rodríguez *et al.* 2023). However, its bio-efficacy depends on the isolation source and life stages of the insect target stages (Islam *et al.* 2023).

Other entomopathogenic fungi genera

The families Cordycipitaceae and Ophiocordycipitaceae have experienced nomenclatural changes in accordance with the International Code of Nomenclature for Algae, Fungi, and Plants. The genus *Hirsutella*, which was reclassified under *Ophiocordyceps*, now has 121 records in the Index Fungorum and 117 in Mycobank. In Mexico, *Hirsutella* is primarily used for mite control. Additionally, the genus *Isaria* was renamed under *Cordyceps*, and the use of *Akanthomyces* has been favored over *Lecanicillium* (Kepler *et al.* 2017). *Akanthomyces lecanii*, the teleomorph of *Cordyceps confragosa*, is used to control whiteflies, hemipterans, and aphids. Other entomopathogenic fungi used in biological control in Mexico include *Cordyceps javanica* (formerly *I. javanica*), which is the primary species of the genus *Cordyceps* used to control whiteflies (Murillo-Alonso *et al.* 2023). Additionally, *Cordyceps mexicana* has potential applications in forest pest control (López-Rodríguez *et al.* 2022).

AGRICULTURAL FUNGI-BASED INSECTICIDES (AFI)

The development of a bioinsecticide is a complex process that requires extensive research and development over several years. The process begins with seeking infected insects or the use of insect baits to obtain entomopathogenic fungi from the soil. These fungi undergo isolation and morphological and molecular characterization. Additionally, the optimal growth conditions are evaluated, including culture media, fermentation type, thermotolerance tests, UV light tolerance, chemical tolerance, tests for synergism and antagonism, and water stress. Also, the biological effectiveness of the bioinsecticide is assessed under both laboratory and field conditions, focusing on metrics such as mean lethal concentration, mean lethal dose, and mean lethal time. Efficient mass production methods are developed, followed by the creation of a suitable formulation. This includes testing the formulation's tolerance to ingredients, quality parameters, hydrophobicity, packaging, and labeling. Further assessments ensure persistence in the field and determine the shelf life, considering both the physical and biological stability of the formulation. Before commercialization, the bioinsecticide must undergo evaluation by regulatory agencies. In Mexico, this involves obtaining authorization and registration from the Comisión Federal para la Protección contra Riesgos Sanitarios (COFEPRIS) in coordination with the

Secretaría de Medio Ambiente y Recursos Naturales (SEMARNAT) and the Secretaría de Agricultura y Desarrollo Rural (SADER).

In Mexico, the study, production, and application of EF in the field began in 1990 in some research centers and mainly at the CNRCB (Zelaya-Molina *et al.* 2022, Rodríguez del Bosque *et al.* 2015). One of the first cases of the development of microbial pest control agents with EF in Mexico was the control of the locust (*Schistocerca piceifrons*) with *M. acridum*, where the CNRCB had an essential role in laboratory and field studies and the diffusion of the technology (Hernández-Velázquez and Arredondo-Bernal 2003). In the mid-90s, the first companies that produced and marketed AFI were consolidated; one of these companies was "Agrobiológico del Noroeste, S.A. de C.V." (Agrobionsa). At the end of the 90s, twenty institutions and private companies producing and marketing beneficial organisms for insect control in Mexico had at least one EF species (Tamez-Guerra *et al.* 2001). By 2001, there were 11 products based on EF, of which five had *B. bassiana* as active ingredient, three had *M. anisopliae*, and another three had *Paecilomyces fumosoroseus.* These fungi were produced by four companies and two laboratories from the Mexican government. In 2010, a total of 28 plants producing biopesticides were documented (17 companies and 11 laboratories of propagation centers and/or units), which mainly produced *B. bassiana*, followed by *M. anisopliae, P. fumosoroseus, Verticillium lecanni, M. anisopliae* var. *acridum* and *Paecilomyces* sp. (García de León & Mier 2010).

According to the "Directorio de Laboratorios Reproductores y Comercializadores de Agentes de Control Biológico DGSV-CNRCB, y DGSV-CNRF-Departamento de Control Biológico (DCB) (SENASICA 2020, 2022)" and the "Registro Sanitario de Plaguicidas, Nutrientes Vegetales de la Comisión Federal para la Protección contra Riesgos Sanitarios (COFEPRIS 2022)", 76 products with EF as an active ingredient are produced and marketed (Tables 1-4). Of these, 53 contain as an active ingredient a single EF species, 23 products of *B. bassiana*, 16 *M. anisopliae*, 7 *I. fumosorosea*, 4 *A. lecanii*, 2 *M. acridum*, and only 1 product that contains *I. javanica.* The remaining products contain two or more EF strains and even a mixture with entomopathogenic bacteria (Table 4). At least 56 other products containing EF were not documented and are not described in the tables because the information provided was not accurate or the label lacked an adequate description, such as the amount of the conidial concentration, the type of formulation, and target pests. Products containing *B. bassiana*, according to the description on the labels and technical sheets, are used to control arthropods belonging to Coleoptera, Hemiptera, Lepidoptera, Orthoptera, Thysanoptera, and Trombidiformes (Table 1). Products that contain *M. anisopliae* as an active ingredient are used to control Coleoptera, Hemiptera, Dermaptera, Diptera, Hymenoptera, Lepidoptera, Orthoptera, Thysanoptera and Trombidiformes (Table 2). In contrast, products containing *I. fumosorosea* aim to control insects of the order Hemiptera (Table 3) and *A. lecanii* controls insects of the orders Homoptera and Hemiptera (Table 3). Sixty-three percent of companies and institutions dedicated to the production and sale of this type of AFI indicate conidia or spores as the active ingredient, while the rest only indicate that the products contain Colony Forming Units (CFU). The formulations of AFI are diverse, and according to the classification of formulations provided by the Food and Agriculture Organization of the United Nations-World Health Organization (FAO-OMS 2017) the 61.8 % of the documented products have a wettable powder (WP) formulation and contain a variable concentration of CFU or conidia in presentations of 100, 200, 240, 250, 300, 400, 500 and 1000 g. The rest of the formulations are diverse, with 5.2 % in the form of emulsifiable concentrate (EC), 14.5 % soluble concentrate (SL), 9.2 % suspension concentrate (SC) and 9.2 % granules (GR).

The formulations of AFI marketed in Mexico differ significantly in the concentration of the active ingredient or the infective units (conidia/gram, conidia/liter, spores/gram, spores/liter, CFU/gram, and CFU/liter).

The taxonomic identity of the marketed AFI usually needs to be more precise due to the complexity of fungal nomenclature, which is constantly revised and changing. For example, according to current taxonomic and phylogenetic reviews, *Nomurea rileyi* belongs to the genus *Metarhizium; Verticillium lecanii* changed to *Lecanicillium lecanii* and now to *Akanthomyces lecanii; Paecilomyces fumosorosea* changed to *Isaria fumosorosea* and now to *Cordyceps fumosorosea* (Table 5).

Table 1. Agricultural Fungal-Based Insecticides (AFI) in Mexico with the entomopathogenic fungus *Beauveria bassiana* as the active ingredient

Commercial Brand *	Formulation type**	Concentration	Presentation	Company	***Target Pest
BIOVERIA®SCG	WP	1.1 × 10^{10} conidia/g	200 g	AGRHUSA AGROBIOLÓGICOS	*Bemisia tabaci*
BEA-SIN®SCG	SL	1.2 × 10^{12} conidia	1L	AGROBIOLÓGICOS DEL NOROESTE	*Bemisia* spp.
BEA-SIN® WP	WP	1.2 × 10^{12} conidia	240 g	AGROBIOLÓGICOS DEL NOROESTE	*Bemisia* spp.
BAUBA®	SC	2 × 10^{6} CFU 2 × 10^{6} CFU	1L	AGRO FISHER	*Amorbia emigratella, Conotrachelus perseae, Copturus aguacatae, Empoasca* sp. *Frankliniella occidentalis, Gracilaria perseae, Heliothrips haemorrhoidalis, Oligonychus punicae, Tetranychus urticae, Sabulodes* spp., *Tetraleurodes* spp.
BIOBROC	WP	1.5 × 10^{12} conidia	300 g	AGROINDUSTRIAS FUNGI AGRICOLA DEL ORIENTE	*Hypothenemus hampei*
ATENTO®	WP	5.3 × 10^{9} CFU/g	250 g	AGROQUIMICOS VERSA	*B. tabaci*
BIO-BASSB	WP	1 × 10^{11}spores	250 g	BIO INTEGRA	*B. tabaci*
BIO X TERRA BB	SC	9 × 10^{8} spores	1L	BIO AGRO CHEMICAL	Lepidoptera
BIOBEA®	WP	1 × 10^{8} CFU/g	250 g	BIOAMIN, AGROBIOTECNOLOGÍA	*Bemisia argentifolii, Chrysodeixis includens, Cydia pomonella, Hypothenemus hampei, Metamasius hemipterus, Spodoptera frugiperda, Thrips Palmi, Trialeurodes vaporariorum*
BERIA MAX	WP	1 × 10^{8} spores	400 g	BIOAGRIS	*B. tabaci*
BEAUVERIA BASSIANA	GR	1 × 10^{10} CFU	200 g	BIO-ORGANIK	*Oligonychus punicae, Thrips tabaci, T. urticae, F. occidentalis, Dactylopius coccus, Phyllophaga* spp. *Plutella xylostella. Trichoplusia* spp. *B. tabaci, Diaphorina litri. Toxoptera aurantii. H. hampei*
BAUVESHOK	WP	1 × 10^{8} CFU	150 g	BIOPRODUCTORA DE JARDINES SOSTENIBLE	*Brevicoryne brassicae, Diaphorina citri, Phyllophaga vetula, Sitophilus zeamais, Sphenarium purpurascens*
RIALÚ INSECTO	WP	1 × 10^{9} conidia/g	250 g	CENTRO DE INVESTIGACIONES Y DESARROLLO AGRÍCOLA	*B. tabaci, P. vetula*
BEAUVERIA BASSIANA	SL	1 × 10^{12} spores	1 L	GREEN IMPORT SOLUTIONS	*Agriotes* sp., *Anthonomus eugenii, Bacteriseda cockerelli, Bemisia* spp., *D. citri, Diabrotica* spp., *Diatraea saccharalis, Schistocerca piceifrons, S. frugiperda,* Empoasca spp., *Erythroneura* spp., *M. hemipterus, Myzus* spp., *Phyllophaga* spp., *Trioza* spp.

BEAUVEB	WP	1.2 × 10^{12} conidia	150 g	LABORATORIO REPRODUCTOR DE ORGANISMOS BENEFICOS DEL SURESTE	*H. hampei, Heilipus lauri, C. aguacatae, B. tabaci, Phyllophaga* spp.
BEAUBA-HIPER	GR	1×10^{10} spores	200 g	MICROVIDA INNOVACIÓN AGRÍCOLA	*B. tabaci, H. hampei, Ostrinia furnacalis, Phyllophaga* spp.
BEAUBASSIL	SC	1 × 10^{10} conidia	1L	BIOTECNOLOGÍA AGROINDUSTRIAL	Coleoptera, Lepidoptera
BEAUBASSIX	WP	1 × 10^{9} CFU/g	300 g	PRODUCTOS MICROBIOLÓGICOS PARA LA AGRICULTURA	Hemiptera, Lepidoptera, Coleoptera
MUSCARDINA BLANCA	WP	1.2 × 10^{12} conidia	250 g	ORGANISMOS BENÉFICOS DE NAYARIT	Coleoptera, Hemiptera
BASSI-HIT	WP	1 × 10^{12} conidia		PLANT BIOMIMIC	Homoptera, Lepidoptera, Coleoptera
PHC® BEA TRON®	WP	1.2 × 10^{12} conidia	240 g	PLANT HEALTH CARE DE MÉXICO	*B. tabaci, Phyllophaga sp., H. hempei, Acigona loftini, Aeneolamoa* spp.
BEAFOL	WP	1.2 × 108 conidia/g	250 g	SONABARI AGROBIOLOGICOS	Hemiptera, Lepidoptera
SPECTRUM BEA B	EC	1.0 × 10^{11} CFU	1 L	ULTRAQUIMIA AGRÍCOLA	*B. tabaci, Copturus aguacatae, H. hampei, Melanaphis sacchari*

* Registered trademark. **Formulation type: emulsifiable concentrate (EC), granulated (GR), soluble concentrate (SL), suspension concentrate (SC), wettable powder (WP) (FAO, WHO, 2017); Colony Forming Units (CFU). ***The scientific names stipulated in this table correspond to what is described in the technical sheet and/or labels of the mentioned products.

Table 2. Agricultural Fungal-Based Insecticides (AFI) in Mexico with species belonging to the genus *Metarhizium* as active ingredients

Commercial Brand *	Formulation type**	Concentration	Presentation	Company	***Target Pest
Microorganism: *Metarhizium anisopliae*					
RIZIUMAX®	WP	1.1 × 10^{10} conidia/g	200 g	AGRHUSA AGROBIOLÓGICOS	*Bemisia tabaci*
META-SIN®	SL	1.2 × 10^{12} conidia/l	1L	AGROBIOLÓGICOS DEL NOROESTE	*Anthonomus eugenii*
META-SIN® WP	WP	1.2 × 10^{12} conidia	240 g	AGROBIOLÓGICOS DEL NOROESTE	*A. eugenii*
ANI MAX	WP	1 × 10^{8} spores	400 g	BIOAGRIS	Hemiptera, Diptera, Hymenoptera, Coleoptera, Thysanoptera, Orthoptera
METABIOSS®	WP	1 × 10^{8} CFU/g	250 g	BIOAMIN, AGROBIOTECNOLOGÍA	*A. eugenii, Agrotis segetum, Anastrepha ludens, Neoleucinodes elegantalis, Otiorhynchus sulcatus, Phyllotreta* spp.
BIO METT	WP	1 × 10^{11} spores	250 g	BIO INTEGRA	*A. eugenii*
METARSIL	SC	2 × 10 conidia/l	1L	BIOTECNOLOGÍA AGROINDUSTRIAL	Coleoptera, Dermaptera Diptera, Hemiptera, Hymenoptera, Lepidoptera, Orthoptera
METARHIZIUM ANISOPLIAE	SL	1 × 10^{12} spores	1L	GREEN IMPORT SOLUTIONS	Coleoptera, Hemiptera, Hymenoptera, Lepidoptera, Orthoptera

META-HIPER	GR	11 × 10^{11} spores	200 g	MICROVIDA INNOVACIÓN AGRÍCOLA	*B. tabaci, Brachystola magna, Dactylopius coccus, D. citri, F. occidentalis, H. hampei, O. punicae, Phyllophaga* sp., *Plutella xylostella, T. urticae, Toxoptera aurantii, Trichoplusia* sp., *Thrips tabaci*
MUSCARDINA VERDE	WP	1.2 × 10^{12} conidia	250 g	ORGANISMOS BENÉFICOS DE NAYARIT	Coleoptera, Lepidotera
PHC® META TRON®	WP	1.2 × 10^{12} conidia	240 g	PLANT HEALTH CARE DE MÉXICO	*Acheta assimilis, Aeneolamia postica, Aeneolamia* sp., *Anthonomus eugenii, Anthonomus gradis, B. tabaci, Schistocerca* spp.
X-RRIZUM	EC	1 × 10^{11} CFU/l	1L	QUÍMICA LUCAVA	*C. aguacatae*
METAFOL	WP	1.2 × 10^{8} conidia/g	250 g	SONABARI AGROBIOLOGICOS	Hemiptera, Lepidoptera
META-TKN	WP	1.3 × 10^{12} conidia	100 g	TIEMELONLA NICH KLUM	*Hypothenemus hampe*
METARIZIANI	WP	1 × 10^{9} CFU/g	300 g	PRODUCTOS MICROBIOLÓGICOS PARA LA AGRICULTURA	Hemiptera, Coleoptera, Homóptera
SPECTRUM META	EC	1×10^{11} CFU	1 L	ULTRAQUIMIA AGRÍCOLA S.A. DE C. V	*C. aguacatae, B. tabaci*
Microorganism: *Metarhizium anisopliae*					
METACRIDUM	WP	1 × 10^{9} CFU/g	300 g	PRODUCTOS MICROBIOLÓGICOS PARA LA AGRICULTURA	Orthoptera
BENERHIZIUM PH CHAPULÍN	WP	2 × 10^{12} conidia	100 g	COMITÉ ESTATAL DE SANIDAD VEGETAL DE GUANAJUATO A. C.	Orthoptera

* Registered trademark. **Formulation type: emulsifiable concentrate (EC), granulated (GR), soluble concentrate (SL), suspension concentrate (SC), wettable powder (WP) (FAO, WHO, 2017); Colony Forming Units (CFU). ***The scientific names stipulated in this table correspond to what is described in the technical sheet and/or labels of the mentioned products.

Table 3. Agricultural Fungal-Based Insecticides (AFI) in Mexico with *Akanthomyces lecanii, Isaria fumosorosea* e *I. javanica* as active ingredients

Commercial Brand *	Formulation type**	Concentration	Presentation	Company	***Target Pest
Microorganism: *A. lecanii (L. lecanii) (V. lecanii)*					
VERTI–SIN®*	SL	1.2 × 10^{12} conidia	1L	AGROBIOLÓGICOS DEL NOROESTE	*Myzus persicae*
EDAY®*	WP	2.1 × 10^{7} conidia/g	250 g	AGROQUIMICOS VERSA	*Aphis gossypii, Bemisia tabaci*
LECANICILLIUM LECANII	SL	1 × 10^{13} spores	1L	GREEN IMPORT SOLUTIONS	*Dysmicoccus* spp.
LECANIS PLUS	WP	1 × 10 CFU 9/g	300 g	PRODUCTOS MICROBIOLÓGICOS PARA LA AGRICULTURA	Thysanoptera

Microorganism: *I. fumosorosea (P. fumosoroseus)*					
PAE-SIN® WP	WP	1.2 × 10^{12} conidia	240 g	AGROBIOLÓGICOS DEL NOROESTE (AGROBIONSA)	*Bemisia* spp.
PAE-SIN®	SL	1.2 × 10^{12} conidia	1L	AGROBIOLÓGICOS DEL NOROESTE (AGROBIONSA)	*Bemisia* spp.
PAECIL	WP	1 × 10^{8} CFU/g	250 g	BIOAMIN AGROBIOTECNOLOGÍA	*B. tabaci, Chrysodeixis includen, Brevicoryne brasisicae, Plutella xylostella Planococcus citri*
BIO FACEF	WP	1 × 10^{11} spores	300 g	BIO INTEGRA	*B. tabaci*
PAECIL	WP	1 × 10^{9} CFU/g	200 g	BIOTERRA INTERNACIONAL	*B. tabaci*
MUSCARDINA ROSA	WP	1.2 × 10^{12} conidia	250 g	ORGANISMOS BENÉFICOS DE NAYARIT	Hemiptera
PHC® PAE TRON®	WP	1.2 × 10^{12} conidia	240 g	ORGANISMOS BENÉFICOS DE NAYARIT	*B. tabaci, B. argentifolii T. vaporarium*
Microorganism: *I. javanica*					
BENEISARI PH DIAPHORINA	WP	2 × 10^{12} conidia	100 g	COMITÉ ESTATAL DE SANIDAD VEGETAL DE GUANAJUATO	*Diaphorina citri*
Microorganism: *I. fumosorosea (P. fumosoroseus), A. lecanii (L. lecanii) (V. lecanii)*					
ISAROL	WP	1 × 10 CFU 9/g	300 g	PRODUCTOS MICROBIOLÓGICOS PARA LA AGRICULTURA	Thysanoptera Hemiptera
LECANICILLUM + ISARIA	GR	1 × 10^{10} CFU	200 g	BIO-ORGANIK	Thysanoptera, Hemiptera Coleoptera

* Registered trademark **Formulation type: emulsifiable concentrate (EC), granulated (GR), soluble concentrate (SL), suspension concentrate (SC), wettable powder (WP) (FAO, WHO, 2017); Colony Forming Units (CFU). ***The scientific names stipulated in this table correspond to what is described in the technical sheet and/or labels of the mentioned products.

Table 4. Agricultural Fungal-Based Insecticides (AFI) in Mexico with various entomopathogenic fungi species as active ingredients

Commercial Brand *	Formulation type**	Concentration	Presentation	Company	***Target Pest
Microorganism: ^ *B. bassiana-M. anisopliae*					
NOVARHIZIUM	SC	1 × 10^{6} conidia 1 × 109 conidia	250 ml	LABORATORIO DE CONTROL BIOLÓGICO DE PROFERTINNOVA	*Schistocerca* spp., *D. coccus*
METHAR®	SC	2 × 10^{6} CFU 2 × 10^{6} CFU	1L	AGRO FISHER	*Schistocerca* spp., *D. coccus*
BEAUVERIA+ METHARHIZIUM	GR	1 × 10^{10} CFU	200 g	BIO-ORGANIK	*Dysmicoccus* spp.
LECANIS PLUS	WP	1 × 10^{13} spores	300 g	PRODUCTOS MICROBIOLÓGICOS PARA LA AGRICULTURA	*Phyllophaga* sp., *B. tabaci, Aeneolamia* sp., *Melanoplus* sp., *Helicoverpa* spp., *Sitophilus* spp.
CUCARA-SUR	WP	1 × 10^{12}conidia	150 g	LAB. REPRODUCTOR DE ORGANISMOS BENEFICOS DEL SURESTE	Blattodea

MICOTIVA	WP	5×10^8 CFU/g 5×10^8 CFU/g	1 K	TECNOLOGÍAS NATURALES INTERNACIONAL	*Brevicoryne* spp., *Dysmicoccus* spp., *Frankliniella* spp., *Bemisia* spp., *Trialeurodes* spp., *Alphitobius* spp., *Aeneolamia* spp., *Diatraea* spp., *Astaena* spp., *Phyllophaga* spp., *Leptopharsa* spp., *Acheta* spp., *Nicentrites* spp.
BAUBA®	SC	2×10^6 CFU 2×10^6 CFU	1L	AGRO FISHER	*B. tabaci*, *F. occidentalis*, *O. punicae*
BIO MA-BB	WP	1×10^{11} spores 1×10^{11} spores	250 g	BIO INTEGRA	*A. eugenii*
PHYTO-CONTROL	GR	1×10^{11} spores	200 g	MICROVIDA INNOVACIÓN AGRÍCOLA	*D. citri*, *F. occidentalis*, *H. hampei*, *O. punicae*, *Phyllophaga* spp, *P. xylostella*, *T. urticae*, *T. aurantii*, *Trichoplusia* spp, *T. tabaci*
Microorganism: *M. anisopliae-M. robertsii*					
META-MR	WP	1×10^{11}conidia	250 g	LABTECSUS	Lepidoptera
Microorganism: *B. bassiana-M. anisopliae-P. fumosoroseus*					
TRI-SIN® WP	WP	2.4×10^{12} conidia	1L	AGROBIOLÓGICOS DEL NOROESTE	*Bactericera cockerelli*
TRI-SIN® CE	EC	2.4×10^{12} conidia	240 g	AGROBIOLÓGICOS DEL NOROESTE	*B. cockerelli*
BIOTECH BMI	SL	1×10^6spores/mL 1×10^6spores/mL 1×10^6spores/mL	1L	BIOGANIKA MEXICANA	*B. tabaci*, *B. cockerelli*, *H. Virescens*, *S. frugiperda*, *Phyllophaga* spp., *Anomala* spp., *P. xylostella*, *Cyclocephala* spp., *Heliothis virescens*, *S. exigua*, *C. aguacatae*
BIODESTRUCTOR	WP	1×10^8 CFU/g	500 g	BIOAGRIS	Hemiptera, Diptera, Hymenoptera, Coleoptera, Thysanoptera, Orthoptera
SPORAX®	WP	3×10^8 CFU/g	250 g	BIOAMIN, AGROBIOTECNOLOGÍA	*B. argentifolii*, *C. pomonella*, *C. includens*, *H. hampei*, *M. hemipterus*, *S. frugiperda*, *T. Palmi*, *T. vaporariorum*
MEPAB	WP	1×10^{12} conidia	150 g	LAB. REP. DE ORGANISMOS BENEFICOS DEL SURESTE	*H. hampei*, *Heilipus lauri*, *C. aguacatae*, *B. tabaci*, *Phyllophaga* spp.
Microorganism: *B. bassiana- L. lecanii- M. anisopliae*					
BEA-MET-PLUS	WP	1.2×10^8 CFU/g 1.2×10^8 CFU/g 1.2×10^8 CFU/g	400 g	GAIA ASESORÍA INTEGRAL AMBIENTAL	Coleoptera, Diptera, Hemiptera, Lepidoptera, Thysanoptera
Microorganism: *B. bassiana- L. lecanii- P. fumosoroseus*					
VER-PAE	WP	1.2×10^8 CFU/g 1.2×10^8 CFU/g 1.2×10^8 CFU/g	400 g	GAIA ASESORÍA INTEGRAL AMBIENTAL	Hemiptera, Thysanoptera
Microorganism: *B. bassiana-N. rileyi- M. anisopliae- L. lecanii- P. fumosoroseus*					
ENTOMAXX 5X2	SL	1×10^7 CFU/ml 1×10^7 CFU/ml 1×10^7 CFU/ml 1×10^7 CFU/ml 1×10^7 CFU/ml	1L	GREENCORP BIORGANIKS DE MÉXICO	Coleoptera, Hemiptera, Lepidoptera

Bio Pest Max®	SL	1×10^7 CFU/ml 1×10^7 CFU/ml 1×10^7 CFU/ml 1×10^7 CFU/ml 1×10^7 CFU/ml	1L	TECNOLOGÍAS AGRIBEST	Coleoptera, Hemiptera, Lepidoptera
Microorganism: *B. bassiana-N. rileyi-B. thuringiensis*					
LARBIOL 2X	SL	1×10^7 CFU/ml 1×10^7 CFU/ml 1×10^7 CFU/ml	1L	GREENCORP BIORGANIKS DE MÉXICO	*Phyllophaga* spp., *S. frugiperda*
Microorganism: *L. lecanii-P. fumosoroseus*					
LEKANY-DUO	GR	1×10^{11} spores	200 g	MICROVIDA INNOVACIÓN AGRÍCOLA.	Hemiptera, Homoptera, Lepidoptera, Orthoptera, Thysanoptera

*Registered trademark. **Formulation type: emulsifiable concentrate (EC), granulated (GR), soluble concentrate (SL), suspension concentrate (SC), wettable powder (WP) (FAO, WHO, 2017); Colony Forming Units (CFU). ***The scientific names stipulated in this table correspond to what is described in the technical sheet and/or labels of the mentioned products.

Table 5. Agricultural Fungal-Based Insecticides (AFI) current names according to the last taxonomic revision (Mycobank, 2023)

Current name	*Basionym	Synonym
Akanthomyces lecanii	*Cephalosporium lecanii*	*Lecanicillium lecanii* *Verticillium lecanii*
Cordyceps fumosorosea	*Isaria fumosorosea*	*Paecilomyces fumosoroseus* *Spicaria fumosorosea*
Cordyceps javanica	*Spicaria javanica*	*Paecilomyces javanicus* *Isaria javanica*
Metarhizium rileyi	*Botrytis rileyi*	*Nomuraea rileyi* *Spicaria rileyi* *Beauveria rileyi*
Purpureocillium lilacinum	*Penicillium lilacinum*	*Paecilomyces lilacinus*

*The original scientific name on which the current name is based

USE OF AFI IN PHYTOSANITARY CAMPAIGNS AND PROGRAMS

Phytosanitary campaigns in Mexico aim to detect, control, and prevent the spread of pests and pathogens from Mexican vegetable production. Epidemiological surveillance, chemical and biological control, and legal activities are carried out to improve the crop's competitiveness (SENASICA 2023).

Among the phytosanitary campaigns that have used AFI are those carried out with *I. javanica* and *M. anisopliae* to control the "Asian citrus psyllid" (*Diaphorina citri*), which is a hemipteran that causes damage to citrus trees, mainly from the Rutaceae family that represents 589,683 ha in 2017 (SENASICA 2019a). From 2012 to 2015, 34,644 ha of citrus trees were treated with the strains CHE-CNRCB 303 and 307 of *I. javanica*, and strain 224 of *M. anisopliae* in the states of Colima, Hidalgo, Jalisco, Nayarit, Oaxaca, San Luis Potosí, Tamaulipas and Veracruz (Sánchez-González *et al.* 2015). During 2018, applications of *M. anisopliae* were carried out on 3,884 ha in the state of Hidalgo in March, in addition to applications of *I. javanica* in June on 770, 2,500 and 16,000 ha, for the states of Campeche, Quintana Roo and Yucatán respectively. It is considered that with the applications of these AFI, a reduction in the psyllid population between 60 to 81.8% has been achieved (SENASICA 2018).

Another relevant pest is the American locust (*Schistocerca* spp.), which is considered among the most harmful pests in the world. Their different species devastate thousands of hectares cultivated worldwide, affecting cereals, fruit trees, legumes, and grasses. The biological control of *S. piceifrons* has been carried out since 2009 using applications of *M. acridum* in the states of Campeche, Chiapas, Hidalgo, Oaxaca, San Luis Potosí, Tabasco, Tamaulipas, Veracruz, and Yucatán. From 2009 to 2016, applications of the fungus were carried out on 11,102 ha which means an annual average of 1,586 ha treated per year. In 2017 and 2018, 886 and 1,090 ha were treated, respectively (SENASICA-DGSV 2016a). Furthermore, the control of grasshoppers of the species *Brachystola magna, B. mexicana, Melanoplus differentialis,* and *Sphenarium purpurascens* has been treated with *M. acridum* in the states of Guanajuato and Tlaxcala with applications on 4,000 and 8,000 ha, respectively since 2011. From 2012 to 2016, applications with *M. acridum* were carried out on 54,256 ha in the states of Chihuahua, Guanajuato, and Tlaxcala (SENASICA-DGSV 2016b). Finally, a campaign from 2009 to 2015 with *I. javanica* strain CHE-CNRCB 305 to control the brown citrus aphid *Toxoptera citricida*, which is a severe threat to citrus farming, was implemented on 12,336 ha (Barrera 2020; SENASICA 2019b).

CONCLUSION

AFI research, production, and application in the field have increased in Mexico since the 1990s. AFI has gained prestige as functional products that control insect pests of fruit, vegetables and cereal crops. Currently, there are 76 commercial products described in this work and 56 products that were not considered in the tables. The most common fungi in AFI are *B. bassiana* and *M. anisopliae*, which are mostly formulated in wettable powders. This review represents a database that can be updated periodically, providing the scientific community and Mexican agriculture with a source of information on AFI.

ACKNOWLEDGEMENTS

All authors acknowledge Facultad de Medicina, Universidad Nacional Autónoma de México (UNAM) for research support. KTMA acknowledges the postdoctoral fellowship from the Dirección General de Asuntos del Personal Académico, Universidad Nacional Autónoma de México (DGAPA, UNAM). The authors thank Hortensia Navarro Barranco and Amelia Pérez Mejía for data searching support. This work was supported by grants from the Consejo Nacional de Ciencia y Tecnología (CONACyT) PDCPN 2015-1247, and the Facultad de Medicina, Universidad Nacional Autónoma de México (UNAM), project 044 /2016 and FM/DI/080/2023.

REFERENCES

Barrera JF. 2020. Conceptos, alcances e implicaciones del control biológico. In: Arredondo-Bernal HC, Tamayo-Mejía F, Rodríguez del Bosque LA (eds.). Fundamento y práctica del control biológico de plagas y enfermedades. 1ª edición. Editorial del Colegio de Postgraduados, Texcoco.Pp. 15-39

Behie SW, Jones SJ, Bidochka MJ. 2015. Plant tissue localization of the endophytic insect pathogenic fungi *Metarhizium* and *Beauveria*. Fungal Ecology 13, 112-119. https://doi.org/10.1016/j.funeco.2014.08.001

Brunner-Mendoza C, Reyes-Montes MR, Moonjely S, Bidochka MJ, Toriello C. 2018. A review on the genus *Metarhizium* as an entomopathogenic microbial biocontrol agent with emphasis on its use and utility in Mexico. Biocontrol Science and Technology 29, 83-102. https://doi.org/10.1080/09583157.2018.1531111

Butt TM, Coates CJ, Dubovskiy IM, Ratcliffe NA. 2016. Entomopathogenic fungi: new insights into host-pathogen interactions. Advanced Genetics 94, 307-64. https://doi.org/10.1016/bs.adgen.2016.01.006

COFEPRIS. 2022. Consulta de registros sanitarios de plaguicidas, nutrientes vegetales y LMR. http://siipris03.cofepris.gob.mx/Resoluciones/Consultas/ConWebRegPlaguicida.asp

FAO-OMS. 2017. Manual sobre la elaboración y uso de las especificaciones de plaguicidas de la FAO y la OMS. Tercera revisión de la primera edición 314 pp. https://www.fao.org/3/i5713s/i5713s.pdf

Faria MR, Wraight SP. 2007. Mycoinsecticides and mycoacaricides: A comprehensive list with worldwide coverage and international classification of formulation types. Biological Control 43, 237-256. http://dx.doi.org/10.1016/j.biocontrol.2007.08.001

García de León S, Mier T. 2010. Visión general de la producción y aplicación de bioplaguicidas en México. Sociedades Rurales Producción Medio ambiente 10(20), 37-63. https://biblat.unam.mx/hevila/Sociedadesruralesproduccionymedioambiente/2010/vol10/no20/2.pdf

Hernández-Velázquez VM, Arredondo-Bernal HC. 2003. Formulación y aplicación de cepas nativas de *Metarhizium anisopliae* var. *acridum* Driver & Milner (Hyphomycetes) para el control de *Schistocerca piceifrons* Walker (Orthoptera: Acrididae) en México. Vedalia 10(8), 5-91.

Herrera-Moreno JF, Benitez-Trinidad AB, Xotlanihua-Gervacio MC, Bernal-Hernández YY, Medina-Díaz IM, Barrón-Vivanco BS, González-Arias CA, Pérez-Herrera N E, Rojas-García AE. 2018. Factores de riesgo de exposición durante el manejo y uso de plaguicidas en fumigadores urbanos. Revista Internacional De Contaminación Ambiental 34, 33-44. https://doi.org/10.20937/RICA.2018.34.esp02.03

Islam SMN, Chowdhury MZH, Mim MF, Momtaz MB, Islam T. 2023. Biocontrol potential of native isolates of *Beauveria bassiana* against cotton leafworm *Spodoptera litura* (Fabricius). Scientific Reports 13, 8331. https://doi: 10.1038/s41598-023-35415-x

Kepler RM, Humber RA, Bischoff JF, Rehner SA. 2014. Clarification of generic and species boundaries for *Metarhizium* and related fungi through multigene phylogenetics. Mycologia 106, 811-829. https://doi.org/10.3852/13-319

Kepler RM, Luangsa-ard JJ, Hywel-Jones NL, Quandt CA, Sung GH, Rehner SA, Aime M C, Henkel TW, San Juan T, Zare R, Chen MJ, Li ZZ, Rossman AY, Spatafora JW, Shrestha B. 2017. A phylogenetic-based nomenclature for Cordycipitaceae (Hypocreales). IMA Fungus 8(2), 335-353. https://doi.org/10.5598/imafungus.2017.08.02.08

Lacey LA, Grzywacz D, Shapiro-Ilan DI, Frutos R, Brownbridge M, Goettel MS. 2015. Insect pathogens as biological control agents: Back to the future. Journal of Invertebrate Pathology 132, 1-41. https://doi.org/10.1016/j.jip.2015.07.009

Li K, Liu J, Geng Z, Xu W, Zhang Z, Chu D, Guo L. 2023. Resistance to dinotefuran in *Bemisia tabaci* in China: status and characteristics. Pest Management Science 79(2), 833-844. https://doi.org/10.1002/ps.7251

López-Rodríguez L, Burrola-Aguilar C, Garibay-Orijel R, Estrada-Zúñiga ME, Matías-Ferrer N, Argüelles-Moyao A. 2022. *Cordyceps mexicana* sp. nov. parasitizing *Paradirphia* sp. moths: A new sister species of the *Cordyceps militaris* complex,-distributed in central Mexican Quercus-Pinus mixed forests. Mycologia 114, 732-747. https://doi.org/10.1080/00275514.2022.2058854

López-Rodríguez L, Burrola-Aguilar C, SanJuan T, Garibay-Orijel R, Argüelles-Moyao A, Estrada-Zúñiga ME, Hernández-Azotea MR. 2023. *Cordyceps* sensu lato: the current state of knowledge in Mexico. Scientia Fungorum 54, 1421e. https://doi.org/10.33885/sf.2023.54.1421

Markets and Markets. 2023. Agricultural Microbials Market by Function (Soil Amendment and Crop Protection), Crop Type (Cereals & grains, Oilseeds & Pulses, Fruits & Vegetables, Type, Mode of Application, Formulation, and Region-Global Forecast to 2027). https://www.marketsandmarkets.com/Market-Reports/agricultural-microbial-market-15455593.html

Mascarin GM, Jaronski ST. 2016. The production and use of *Beauveria bassiana* as microbial insecticide. World Journal of Microbiology and Biotechnology 32, 1-26. https://doi.org/10.1007/s11274-016-2131-3

Mongkolsamrit S, Khonsanit A, Thanakitpipattana D, Tasanathai K, Noisripoom W, Lamlertthon S, Himaman W, Houbraken J, Samson RA, Luangsa-ard J. 2020. Revisiting *Metarhizium* and the description of new species from Thailand. Studies in Mycology 95(1), 171-251. https://doi.org/10.1016/j.simyco.2020.04.00

Montesinos-Matías R, Ayala-Zermeño MA, Berlanga-Padilla AM, Avalos AJJ, Arredondo-Bernal HC. 2020. Colección de hongos entomopatógenos del centro nacional de referencia de control biológico, México. Boletín de la Federación Latinoamericana de Colecciones de Cultivos (FELACC), Ciudad de México. .http://felacc.cinvestav.mx/boletin/29.pdf

Murillo-Alonso KT, Hernández-Velázquez VM, Salazar-Schettino PM, Cabrera-Bravo M, Toriello C. 2019. Effects of *Metarhizium anisopliae* on *Meccus pallidipennis* (Hemiptera: Reduviidae) over different types of wall surfaces. Biocontrol Science and Technology 29(5), 466-477. https://doi.org/10.1080/09583157.2019.1566438

Murillo-Alonso KT, Salazar-Magallón JA, Olarte-Lozano M, Peña-Chora G, Hernández-Baltazar E, Toriello C, Hernández-Velázquez VM. 2023. Evaluation of *Isaria javanica* (Hypocreales: Cordycipitaceae) oil dispersion formulations for the control of *Bemisia tabaci* (Hemiptera: Aleyrodidae). International Journal of Tropical Insect Science 43(6), 2179 - 2187. https://doi.org/10.1007/s42690-023-01120-5

Ortiz A, Sansinenea E. 2023. Microbial-based biopesticides: commercialization and regulatory perspectives In: Development and Commercialization of Biopesticides. Opender K (Ed.). Academic Press. 103-118 pp. https://doi.org/10.1016/B978-0-323-95290-3.00020-0

Ortiz-Urquiza A, Keyhani NO. 2013. Action on the surface: Entomopathogenic fungi versus the insect cuticle. Insects 4(3), 357-74. https://doi.org/10.3390/insects4030357

Pathak VM, Verma VK, Rawat BS, Kaur B, Babu N, Sharma A, Dewali S, Yadav M, Kumari R, Singh S, Mohapatra A, Pandey V, Rana N, Cunill JM. 2022. Current status of pesticide effects on environment, human health and it's eco-friendly management as bioremediation: A comprehensive review. Frontiers in Microbiology 13, 962619. https://doi.org/10.3389/fmicb.2022.962619

Rehner SA, Minnis AM, Sung GH, Luangsa-ard JJ, Devotto L, Humber RA. 2011. Phylogeny and systematics of the anamorphic, entomopathogenic genus *Beauveria*. Mycologia 103(5), 1055-73. https://doi.org/10.3852/10-302

Rodríguez del Bosque LA, Arredondo Bernal HC, Williams T, Barrera-Gaytán JF. 2015. Pasado, presente y perspectivas del control biológico en México. In: Arredondo Bernal HC, Rodríguez del Bosque LA (eds.). Casos de Control Biológico en México, vol. 2. Biblioteca Básica de Agricultura, Editorial del Colegio de Postgraduados, Texcoco. Pp. 17-28.

Sánchez-González JA, Mellín-Rosas MA, Arredondo-Bernal AC, VizcarraValdez NI, González-Hernández A, Montesinos-Matías R. 2015. Psílido asiático de los cítricos, *Diaphorina citri* (Hemiptera: Psyllidae). In: Arredondo-Bernal HC, Rodríguez-del-Bosque LA (eds.). Casos de Control Biológico en México, Vol. 2, Editorial Biblioteca Básica de Agricultura, Colegio de Postgraduados, Texcoco. Pp. 339-372.

SENASICA-DGSV 2016a. Langosta Centroamericana [*Schistocerca piceifrons piceifrons* (Walker, 1870) (Orthoptera: Acrididae). Ficha Técnica. Servicio Nacional de Sanidad, Inocuidad y Calidad Agroalimentaria- Dirección General de Sanidad Vegetal- Centro Nacional de Referencia Fitosanitario- Grupo Especialista Fitosanitario, Tecámac.

SENASICA-DGSV 2016b. Chapulines de importancia económica en México: *Brachystola magna, Brachystola mexicana, Melanoplus differentialis, Sphenarium purpurascens* y *Taeniopoda* spp. (Orthoptera: Romaleidae). Ficha Técnica. SADER-SENASICA. Dirección General de Sanidad Vegetal- Centro Nacional de Referencia Fitosanitaria, Tecámac.

SENASICA 2018. Quinto informe mensual Campaña contra Huanlonbing de los cítricos. https://www.gob.mx/cms/uploads/attachment/file/340214/Informe_mayo_2018_HLB.pdf

SENASICA 2019a. Psílido asiático de los cítricos (*Diaphorina citri*). Fecha de la última actualización: mayo de 2019. Ficha Técnica 77. Servicio Nacional de Sanidad, Inocuidad y Calidad Agroalimentaria-Dirección General de Sanidad Vegetal- Programa de Vigilancia Epidemiológica Fitosanitaria, Ciudad de México.

SENASICA 2019b. Pulgón café de los cítricos *Toxoptera citricida* (Kirkaldt). Servicio Nacional de Sanidad, Inocuidad y Calidad Agroalimentaria- Dirección General de Sanidad. https://www.gob.mx/cms/uploads/attachment/file/458932/37._Pulgon_cafe_de_los_citricos.pdf

SENASICA. 2020. Directorio de Laboratorios Reproductores y Comercializadores de Agentes de Control Biológico en México. CNRCB-DGSV. https://www.gob.mx/cms/uploads/attachment/file/654361/DIRECTORIO_DE_LABS_COMERCIALIZADORES-2021.pdf

SENASICA. 2022. Directorio de Laboratorios Reproductores y Comercializadores de Agentes de Control Biológico en México DGSV-CNRF-DCB. https://www.gob.mx/senasica/documentos/directorio-de-laboratorios-reproductores-y-comercializadores-de-agentes-de-control-biologico

SENASICA 2023. Campañas y programas fitosanitarios. https://www.gob.mx/senasica/acciones-y-programas/campanas-fitosanitarias

Tamez-Guerra P, Galán-Wong LJ, Medrano-Roldán H, García-Gutiérrez C, Rodríguez-Padilla C, Gómez-Flores RA, Tamez-Guerra RS. 2001. Bioinsecticidas: su empleo, producción y comercialización en México. Ciencia UANL 4(2), 143-152. https://www.redalyc.org/pdf/402/40240205.pdf

Vega FE. 2018. The use of fungal entomopathogens as endophytes in biological control: A review. Mycologia 110(1), 4-30. https://10.1080/00275514.2017.1418578

Zelaya-Molina LX, Chávez-Díaz IF, de los Santos-Villalobos S, Cruz-Cárdenas CI, Ruiz-Ramírez S, Rojas-Anaya E. 2022. Biological pest control in Mexican agriculture. Revista Mexicana de Ciencias Agrícolas 27, 69-79. https://doi.org/10.29312/remexca.v13i27.3251

Zhang WJ. 2018. Global pesticide use: Profile, trend, cost/benefit and more. Proceedings of the International Academy of Ecology and Environment Sciences 8(1), 1-27. http://www.iaees.org/publications/journals/piaees/articles/2018-8(1)/global-pesticide-use-profile-trend-cost-benefit.pdf

Zimmermann G. 2007. Review on safety of the entomopathogenic fungi *Beauveria bassiana* and *Beauveria brongniartii*. Biocontrol Science and Technology 17(6), 553-596. https://doi.org/10.1080/09583150701309006