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Perspective

Mycoinsecticides and Mycoacaricides: A comprehensive list with worldwide coverage and international classification of formulation types ☆

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Abstract

A substantial number of mycoinsecticides and mycoacaricides have been developed worldwide since the 1960s. Here we present an updated, comprehensive list of these products. At least 12 species or subspecies (varieties) of fungi have been employed as active ingredients of mycoinsecticides and mycoacaricides for inundative and inoculative applications, although some are no longer in use. Products based on *Beauveria bassiana* (33.9%), *Metarhizium anisopliae* (33.9%), *Isaria fumosorosea* (5.8%), and *B. brongniartii* (4.1%) are the most common among the 171 products presented in this paper. Approximately 75% of all listed products are currently registered, undergoing registration or commercially available (in some cases without registration), whereas 15% are no longer available. We were unable to determine the status of the remaining 10%. Insects in the orders Hemiptera, Coleoptera, Lepidoptera, Thysanoptera, and Orthoptera comprise most of the targets, distributed among at least 48 families. A total of 28 products are claimed to control acarines (mites and ticks) in at least 4 families, although only three products (all based on *Hirsutella thompsonii*) were exclusively developed as acaricides. Eleven different technical grade active ingredients or formulation types have been identified, with technical concentrates (fungus-colonized substrates) (26.3%), wettable powders (20.5%) and oil dispersions (15.2%) being most common. Approximately 43% of all products were developed by South American companies and institutions. Currently, what may be the largest single microbial control program using fungi involves the use of *M. anisopliae* for control of spittlebugs (Cercopidae) in South American sugarcane and pastures.

Keywords: Entomopathogenic fungi; Mycopesticides; Mycoinsecticides; Mycoacaricides; Formulations; Microbial control; Augmentation; IPM

1. Introduction

The first attempt to control a pest with a fungal agent was carried out in Russia in 1888, when the fungus now known as *Metarhizium anisopliae* (Metschn.) Sorokīn was mass produced on beer mash and sprayed in the field for control of the beet weevil *Cleonus punctiventris* (Germar) (Lord, 2005). Boverin, a *Beauveria bassiana*-based mycoinsecticide for control of the Colorado potato beetle and codling moth in the former USSR, was developed in 1965 (Kendrick, 2000). Mycar, a mycoacaricide based on *Hirsutella thompsonii* Fisher, was granted a full registration by the US Environmental Protection Agency in 1981 for control of the citrus rust mite, *Phyllocoptruta oleivora* (Ashmead), in the United States (McCoy, 1986). Research and development efforts have increased markedly in recent years, and a considerable number of fungus-based biopesticides have been developed for control of insects and

☆ The USDA (USA), Cornell University (USA) and EMBRAPA (Brazil) neither guarantees nor warrants the quality and claims of the commercial products mentioned in this paper, and the use of the name by USDA/Cornell University/EMBRAPA implies no approval of products.

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acarines (mites and ticks) in agricultural, urban, forest, livestock and aquatic environments. In the following discussion, these mycoinsecticides/mycoacaricides will be referred to as mycopesticides, a term that also embraces other fungal biological products not considered in this paper, such as mycoherbicides and mycofungicides.

There are many recent reviews discussing the efficacy, contemporary advances, future trends, and regulatory aspects of mycopesticides (Copping and Menn, 2000; Neale, 2000; Inglis et al., 2001; Wraight et al., 2001; Castrillo et al., 2005). Although numerous lists of developed mycopesticides are available (Tengerdy and Szakács, 1998; Butt et al., 1999; Butt and Copping, 2000; Hajek et al., 2001; Stewart, 2001; Wraight et al., 2001; Leite et al., 2003a; Copping, 2004; Hynes and Boyetchko, 2006), many of these are deficient, especially in terms of worldwide coverage.

This study aimed to assemble a comprehensive list of mycopesticides developed worldwide over the last four decades. In addition, we have attempted to review and standardize the nomenclature of formulation types so far employed for these biocontrol agents. Use of fungal agents through conservation and classical biological control strategies is discussed elsewhere (Pell et al., 2001; Hajek et al., 2003; Shah and Pell, 2003).

2. Products and formulations

A complete list of mycopesticides for insect and acarine control from different regions of the globe was prepared from information obtained from a variety of sources. In addition to scientific publications, an array of technical publications, personal communications, company brochures, and websites, including those of manufacturers and governmental agencies, were used. Websites were accessed during the period between October, 2005 and September, 2006, and personal communications were obtained through April, 2007.

2.1. Fungal products

For the purpose of this paper, mycopesticides are defined as products based on living fungal propagules intended to control pests through inundative or inoculative applications. Propagule types present in most products are classified as hyphae (mycelia), blastospores, or conidia. When the information could be found, conidia were further characterized as aerial or submerged conidia. When available information was insufficient to identify conidia versus blastospores, the propagules were listed simply as asexual spores. Target pests were identified to order and, when possible, to family. The diverse insects in the order Hemiptera were identified also to suborder. The classification of insects follows Triplehorn and Johnson (2005).

Our work presents a comprehensive list of mycopesticides that are registered, undergoing registration or marketed, in some cases without being registered. A few preparations developed but never registered or commercialized, such as the ultra-low volume suspension of Mycotrol-OF, are also considered. Mycopesticides commercialized without registration and, in the other extreme, registered products that currently are not being commercialized, are included in the list of products as well. Names of manufacturers are listed according to best available information. However, due to difficulties in tracking the ever-changing relationships among companies, the manufacturer's names mentioned may in some cases refer to licensees or distributors that do not operate manufacturing facilities.

Products with no trade names (usually products undergoing a registration process or unformulated materials sold directly to end users) are included when it was possible to determine that they were commercialized for at least some period of time. For this reason, some names (or lack thereof) might be provisional. Products distributed without charge or sold at subsidized prices to end users by non-profit organizations, such as grower associations, as well as mycopesticides derived from on-farm production are not included. Technical products used solely for formulation of end-products also are not listed, e.g., Troy Boverin, Technical Laginex, PFR-97 MUP, and others. Finally, although molecular systematics studies have shown the proximity of microsporidians to zygomycete fungi (Edlind et al., 1996; Keeling, 2003), these microorganisms were not considered in this paper.

2.2. Fungal formulations

We have attempted to identify formulation types based on the CropLife International two-letter coding system for technical and formulated pesticides (CropLife International, 2002). The international coding system defines approximately 100 different formulation types for pesticides in general, and most of the formulation types described for the mycopesticides listed herein can be classified within this system. In a few cases, we found it difficult to match existing mycopesticide formulations with the formulation types defined by the international code. In these cases we have selected the defined type of formulation that best fits the mycopesticide and have added brief notations on specific incongruities. Some of the definitions we present also incorporate slightly modified definitions used by FAO/WHO (2002) to describe biopesticides based on entomopathogenic bacteria. Wording taken directly from the CropLife International (2002) or FAO/WHO (2002) definitions are presented in italics and quotation marks. Definitions are from the CropLife International coding system unless otherwise indicated.

2.2.1. Technical grade active ingredients (Technical products)

FAO/WHO (2002) applies the generic term technical grade active ingredient to both technical material and technical concentrate.

Technical material (TC). "*An active ingredient isolated (as far as is practicable) from the starting materials, solvents, etc., used to produce it*" (FAO/WHO, 2002). For entomopathogenic fungi, the starting materials are usually the liquid or solid culture substrates. Technical materials are usually the basis for all other formulation types, although in some circumstances they may be used as end-products. According to the CropLife definition, technical materials may include *"associated impurities and small amounts of necessary additives."* Purification "as far as practicable" is generally considered to result in impurity residues comprising <10% of the product weight (T. S. Woods, Chair, Specifications Expert Group, CropLife International, personal communication). In our understanding, conidia or other propagule types isolated from the culture together with associated impurities would fall into this category, also referred to as technical powder (Burges and Jones, 1998).

Technical concentrate (TK). A material consisting of the active ingredient together with related byproducts of the production process and free of any added modifying agents except for small amounts of stabilizers and free-flow agents, if necessary. This definition is a slight modification of the definition presented by FAO/WHO (2002) for bacterial technical concentrates. According to FAO/WHO, a TK should also be free of "visible extraneous matter", but the term extraneous matter is not defined, and in our judgment, the FAO/WHO definition fits fungal biopesticides that include components of the spent culture media, e.g., fungus-colonized cereal grains or whole-culture broths. In these cases, there have been no attempts to separate the active ingredient from the substrate. Included in this category, fungus-colonized solid substrates may contain variable proportions of sporulating mycelia and spores, depending on factors such as age of culture and batch. In some countries they are routinely used as end-products through direct incorporation into soil. Alternatively, the active ingredient may be extracted before application (e.g., by washing and sieving, often with the aid of surfactants). In our paper, for all technical concentrates based on solid substrates we consider the propagule type as being conidia + hyphae (C+H), although frequently the vast majority of propagules at the time of sale may be either spores or hyphae. For products produced in liquid media, mixtures of submerged conidia, blastospores, or hyphae may be present.

2.2.2. Formulation types

Wettable powder (WP). "*A powder formulation to be applied as a suspension after dispersion in water.*" In our understanding, WP formulations must be ready-to-use. Thus, products such as hydrophobic technical materials that do not include additives that render them miscible in water (such as surfactants or clays) would not fall in this category.

Granule (GR). "*A free-flowing solid formulation of a defined granule size range ready for use.*" Although technical concentrates comprising microbe-colonized granular substrates may resemble and function as granular formulations, the term granule generally refers to more elaborated formulations with particles of controlled and uniform size and with the active ingredient strongly adhered to or incorporated into the granule. Thus, fungus-colonized cereal grains are not included under this definition.

Bait (ready for use) (RB). "*A formulation designed to attract and be eaten by the target pests.*" This definition is generally applicable to mycopesticides; however, because most fungal pathogens infect their hosts via direct penetration of the cuticle, ingestion may be of little consequence, and baits may therefore be based on attractants other than food.

Water dispersible granule (WG). "*A formulation consisting of granules to be applied after disintegration and dispersion in water.*"

Contact powder (CP). "*Insecticidal formulation in powder form for direct application.*" Free-flowing powders suitable for dusting are termed dustable powders (DP) under the CropLife International coding system. However, other than a few early preparations produced by nonprofit organizations, we did not identify any mycoinsecticides formulated specifically for broadcast application as dusts. Thus, we have categorized all powders that do not fit any of the previously mentioned formulation types as contact powders.

Suspension concentrate (=flowable concentrate) (SC). "*A stable suspension of active ingredient(s) in water, intended for dilution with water before use.*"

Oil miscible flowable concentrate (=oil miscible suspension) (OF). "*A stable suspension of active ingredient(s) in a fluid intended for dilution in an organic liquid before use.*"

Ultra-low volume (ULV) suspension (SU). "*A suspension ready for use through ULV equipment.*"

Oil dispersion (OD). "*A stable suspension of active ingredient(s) in a water-immiscible fluid, which may contain other dissolved active ingredient(s), intended for dilution in water before use.*" In practice, oil dispersions contain emulsifiers to render the mixture miscible in water for spraying (T. S. Woods, personal communication). The word "stable" in this and other of the abovementioned formulations indicates that the active ingredient does not settle out to a non-resuspendable cake during storage (T. S. Woods, personal communication). Here, we consider the definition to include suspensions that tend to settle, but which are designed to be readily resuspendable by the user via manual agitation. Oil dispersions of entomopathogenic fungi have been referred to most commonly in the literature as emulsifiable suspensions or emulsifiable oil suspensions and identified by the abbreviation ES. However, under the Croplife International code, the abbreviation ES refers to emulsions for seed treatments.

3. Overview of mycopesticides

Mycoinsecticides and mycoacaricides are listed alphabetically by genus and species in Table 1. To date, at least

Table 1
Fungal species and varieties developed into mycoinsecticides/mycoacaricides and their commercial status

Species/Varieties[a,b]	No. Products	Commercial status[c]		
		Active	Inactive	ND
Fungi: Anamorphic Hypocreales				
Aschersonia aleyrodis Webber	1 (0.6%)	0	1	0
Beauveria bassiana (Bals.) Vuill.	58 (33.9%)	45	9	4
Beauveria brongniartii (Sacc.) Petch	7 (4.1%)	5	0	2
Hirsutella thompsonii F.E.Fisher	3 (1.8%)	1	1	1
Isaria fumosorosea Wize	10 (5.8%)	7	1	2
Isaria sp.	1 (0.6%)	1	0	0
Lecanicillium longisporum (Petch) R.Zare & W.Gams	2 (1.2%)	2	0	0
Lecanicillium muscarium (Petch) R.Zare & W.Gams	3 (1.8%)	3	0	0
Lecanicillium sp.	11 (6.4%)	10	0	1
Metarhizium anisopliae (Metschn.) Sorokīn	58 (33.9%)	44	10	4
Metarhizium anisopliae var. *acridum* Driver & Milner	3 (1.8%)	3	0	0
Nomuraea rileyi (Farl.) Samson	1 (0.6%)	0	0	1
Fungi: Anamorphic species identified as *Sporothrix insectorum* de Hoog & H.C.Evans[d]	3 (1.8%)	2	1	0
Fungi: Zygomycota: Zygomycetes: Entomophthorales *Conidiobolus thromboides* Drechsler	2 (1.2%)	1	1	0
Chromista: Oomycota: Oomycetes: Pythiales *Lagenidium giganteum* Couch	1 (0.6%)	1[e]	0	0
Mixes (2 or more species)	7 (4.1%)	4	1	2
TOTAL	171 (100%)	129 (75.4%)	25 (14.6%)	17 (9.9%)

[a] Fungal classification based on Kirk et al. (2001).
[b] Scientific names according to database Index Fungorum (http://www.indexfungorum.org/).
[c] Availability of product is informed as follows: Active, product currently registered, undergoing registration or available (commercially or upon request) in the period between October/2005 and May/2006; Inactive, product no longer available in the market (or developed but never submitted to registration or marketed); ND, current status of product could not be determined.
[d] Further identification of commercial isolates required since isolates are not true *Sporothrix*.
[e] Registered but not currently commercialized.

12 species or subspecies (varieties) of fungi have been employed as the active ingredients in these products. This number will likely increase into the foreseeable future as molecular studies reveal cryptic species within large genera. Classifications at the generic level are also undergoing rapid change. In this work, we have adopted those recent taxonomic changes that we view as strongly supported in the published literature. Most notably, insect pathogenic fungi previously classified as *Verticillium* spp. have been placed in a new genus, *Lecanicillium* (Gams and Zare, 2001; Zare and Gams, 2001), and many insect pathogenic *Paecilomyces* species (including *P. fumosoroseus*) have been transferred to the genus *Isaria* (Hodge et al., 2005; Luangsa-Ard et al., 2005). Some species identified in the table are in urgent need of additional taxonomic work. Recent molecular studies, for example, indicate that isolates of fungi identified as *Sporothrix insectorum* de Hoog & H.C.Evans, currently used in Brazil for control of the lace bug *Leptopharsa heveae* Drake & Poor in rubber tree plantations, belong to more than one species and are not true *Sporothrix* species (K.T. Hodge, Cornell University, personal communication). In the realm of commerce, an unfortunate outcome of taxonomic revision is the emergence of disparities between the names of products and the fungi upon which they are based (as many product trade names are derived from the scientific names of their active ingredients). Product developers should consult fungal systematists before naming their products.

For most fungal species/subspecies listed, there is at least one product that is currently registered (or undergoing registration), or marketed; however, a few species are apparently no longer commercially available. These include *Aschersonia aleyrodis* Webber and *Nomuraea rileyi* (Farl.) Samson (the availability of the only listed *N. rileyi* product could not be determined). *Lagenidium giganteum* Couch is registered but not currently available. With the exception of one species in the phylum Zygomycota and another in the kingdom Chromista (=Stramenipila or Straminopila), all agents comprising this list are anamorphic fungi. *B. bassiana* (Bals.) Vuill., *M. anisopliae* (Metschn.) Sorokīn, *Isaria fumosorosea* Wize, *Beauveria brongniartii* (Sacc.) Petch, and *Lecanicillium* spp., are the main active ingredients of listed products. We believe that approximately two-thirds of all listed products are currently registered, undergoing registration or marketed.

During the last four decades, over 80 companies worldwide have developed 171 mycoinsecticides and mycoacaricides (Table 2). This contrasts sharply with the situation less than three decades ago, when only one commercial mycoinsecticide was available (Ignoffo and Anderson,

Table 2
Fungi developed for control of insects and acarines. List organized by fungal species and within each species by region (Europe, Africa, Asia, Oceania, North America, Central America, and South America). Within each regin, countries are listed in alphabetical order

Country(ies) where undergoing registration, registered or marketed	Trade name[a]	Propagule(s)/ Formulation[b]	Claimed Target(s) (Orders and Families)	Manufacturer	Source(s)[c]
Aschersonia aleyrodis					
Former USSR	Aseronia**	C/TC	Hemiptera (Aleyrodidae)	Gosagroprom, Former USSR	Ignoffo and Anderson (1979), M. Shternshis (personal communication)
Beauveria bassiana					
Czech Republic	Boverol** (=Boverol-Spofa)	C/WP	Coleoptera (Chrysomelidae)	Fytovita, Czech Republic	Kreutz et al. (2004), Wraight et al. (2001), Z. Adamék (personal communication)
Czech Republic	Boverosil**	C/WP (alone or combined with chemical pesticides)	Coleoptera (Curculionidae) + other stored-product pests (not specified)	NI	Feng et al. (1994), Hluchý and Samšiňáková (1989), Z. Adamék (personal communication)
France	Ostrinil**	C+H/TK	Lepidoptera (Crambidae)	Natural Plant Protection (NPP), France	Wraight et al. (2001), Shah and Goettel (1999)
Spain	Trichobass-L*	C/OD	Coleoptera (Curculionidae, Scarabaeidae), Lepidoptera (Castniidae, Pieridae), Hemiptera (Aleyrodidae), Thysanoptera (Thripidae) + Acari (Tetranychidae)	Trichodex S.A., Spain	Website[1]
Spain	Trichobass-P*	C/WP	Coleoptera (Curculionidae, Scarabaeidae), Hemiptera (Aleyrodidae) + Acari (Tetranychidae)	Trichodex S.A., Spain	Website[1]
South Africa	Bb Plus*	A/WP	Hemiptera (Aphididae) + Acari (Tetranychidae)	Biological Control Products SA (Pty) Ltd, South Africa	Website[2]
South Africa	Bb Weevil*	A/CP	Coleoptera (Curculionidae)	Biological Control Products SA (Pty) Ltd, South Africa	Website[2]
India	BioGuard Rich*	A/NI	Coleoptera (Curculionidae, Scarabaeidae), Hemiptera (Aleyrodidae, Aphididae), Lepidoptera (Crambidae), Thysanoptera (Thripidae)	Plantrich Chemicals & Biofertilizers Ltd, India	Website[3]
India	Bio-Power*	A/WP	Coleoptera (Curculionidae, Scarabaeidae), Hemiptera: Auchenorrhyncha (Cicadellidae, Delphacidae), Lepidoptera (Plutellidae)	T.Stanes & Company Limited, India	Copping (2004), Website[4]
India	Racer*	A/WP	Lepidoptera (Noctuidae) + others (not specified)	Agri Life, India	Copping (2004), Website [5]
Japan	Biolisa-Madara*	C+H/TK (fiber band)	Coleptera (Cerambycidae)	Nitto Denko, Japan	M. Shimazu (personal communication)
Russia	Boverin*	B/WP	Hemiptera (Aleyrodidae), Thysanoptera (Thripidae) + Acari (Tetranychidae)	Biodron, Russia	Shternshis (2004), M. Shternshis (personal communication)
Russia	Boverin*	B/NI (liquid suspension)	Hemiptera (Aleyrodidae), Thysanoptera (Thripidae) + Acari (Tetranychidae)	Biodron, Russia	Shternshis (2004), M. Shternshis (personal communication)
Former USSR	Boverin**	C or S+B/WP (alone or combined with chemical insecticides)	Coleoptera (Chrysomelidae), Lepidoptera (Tortricidae)	Glavmikrobioprom, Former USSR	Feng et al. (1994), Ferron (1981), Ignoffo and Anderson (1979)
Mexico	Bea-Sin*	C/WP	Coleoptera (Curculionidae, Scarabaeidae), Hemiptera (Aleyrodidae)	Agrobiologicos del Noroeste S.A. de C.V. (Agrobionsa), Mexico	Wraight et al. (2001), A. Paez (personal communication), Company brochure

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Table 2 (*continued*)

Country(ies) where undergoing registration, registered or marketed	Trade name[a]	Propagule(s)/ Formulation[b]	Claimed Target(s) (Orders and Families)	Manufacturer	Source(s)[c]
Mexico	Bea-Sin*	C/OD	Coleoptera (Curculionidae, Scarabaeidae), Hemiptera (Aleyrodidae)	Agrobiologicos del Noroeste S.A. de C.V. (Agrobionsa), Mexico	A. Paez (personal communication), Company brochure
Mexico	Bio-Fung*	A/NI	Orthoptera	Centro de Sanidad Vegetal de Guanajuato (CESAVEG), Mexico	Guerra et al. (2001), P. Guerra (personal communication)
USA	Baits Motel Stay Awhile-Rest Forever* (previously: Healthy Indoors Brand, Ant and Cockroach Bait Station)	C/RB	Hymenoptera (Formicidae)	GlycoGenesys, Inc., USA (previously: SafeScience, Inc., USA)	Website[6], R. Pereira (personal communication)
USA	Balence*	C/OD	Diptera (Muscidae)	Jabb of the Carolinas Inc., USA	Kaufman et al. (2005), Website[6], L. Castrillo (personal communication)
USA, Mexico, Denmark, Italy, Spain, Sweden, Japan	BotaniGard ES*	C/ OD	Coleoptera (Curculionidae, Scarabaeidae), Hemiptera (Miridae, Aleyrodidae, Aphididae, Pseudococcidae, Psyllidae), Thysanoptera (Thripidae)	Laverlam International Corporation, USA (previously: Emerald BioAgriculture Corp., USA; Mycotech Corp., USA)	Kabaluk and Gazdik (2005), Wraight et al. (2001), Website[7]
USA, Mexico, Denmark, Italy, Spain, Sweden, Japan	BotaniGard 22 WP*	C/WP	Coleoptera (Curculionidae, Scarabaeidae), Hemiptera (Miridae, Cicadellidae, Fulgoridae, Aleyrodidae, Aphididae, Pseudococcidae, Psyllidae), Thysanoptera (Thripidae)	Laverlam International Corporation, USA (previously: Emerald BioAgriculture Corp., USA; Mycotech Corp., USA)	Kabaluk and Gazdik (2005), Wraight et al. (2001), Website[7], Company brochure
USA	CornGard**	C/GR	Lepidoptera (Crambidae)	Mycotech Corp., USA	Hajek et al. (2001), Shah and Goettel (1999)
USA, Mexico, Denmark, Italy, Sweden	Mycotrol ES*	C/OD	Coleoptera (Chrysomelidae, Curculionidae, Scarabaeidae), Hemiptera (Miridae, Cicadellidae, Fulgoridae, Aleyrodidae, Aphididae, Pseudococcidae, Psyllidae), Lepidoptera (Crambidae), Orthoptera (Acrididae, Tettigoniidae), Thysanoptera (Thripidae)	Laverlam International Corporation, USA (previously: Emerald BioAgriculture Corp., USA; Mycotech Corp., USA)	Kabaluk and Gazdik (2005), Wraight et al. (2001), Website[7]
USA, Mexico, Denmark, Italy, Sweden	Mycotrol-O*	C/OD	Coleoptera (Chrysomelidae, Curculionidae, Scarabaeidae), Hemiptera (Miridae, Cicadellidae, Fulgoridae, Aleyrodidae, Aphididae, Pseudococcidae, Psyllidae), Lepidoptera (Crambidae, Noctuidae, Pieridae, Plutellidae), Orthoptera (Acrididae, Tettigoniidae), Thysanoptera (Thripidae)	Laverlam International Corporation, USA (previously: Emerald BioAgriculture Corp., USA; Mycotech Corp., USA)	Website[7], Company brochure
USA	Mycotrol OF**	C/SU	Orthoptera (Acrididae, Tettigoniidae)	Mycotech Corp., USA	S. Jaronski (personal communication)
USA	Mycotrol OF**	C/OD (also for ULV applications)	Orthoptera (Acrididae, Tettigoniidae)	Mycotech Corp., USA	S. Jaronski (personal communication)

Table 2 (*continued*)

Country(ies) where undergoing registration, registered or marketed	Trade name[a]	Propagule(s)/ Formulation[b]	Claimed Target(s) (Orders and Families)	Manufacturer	Source(s)[c]
USA, Mexico, Denmark, Italy, Sweden	Mycotrol WP*	C/WP	Coleoptera (Chrysomelidae, Curculionidae, Scarabaeidae), Hemiptera (Miridae, Cicadellidae, Fulgoridae, Aleyrodidae, Aphididae, Pseudococcidae, Psyllidae), Thysanoptera (Thripidae), Lepidoptera (Crambidae), Orthoptera (Acrididae, Tettigoniidae)	Emerald BioAgriculture Corp., USA (previously: Mycotech Corp., USA)	Kabaluk and Gazdik (2005), Wraight et al. (2001), Website[6]
USA, Mexico, Greece, Italy, Spain, Switzerland	Naturalis L* (=Fermone Naturalis L-225)	C/OD	Coleoptera (Chrysomelidae, Curculionidae, Scarabaeidae), Diptera (Ephydridae, Mycetophilidae, Sciaridae, Tipulidae), Hemiptera (Lygaeidae, Miridae, Cercopidae, Cicadellidae, Aleyrodidae, Aphididae, Pseudococcidae, Psyllidae), Hymenoptera (Formicidae), Lepidoptera (Crambidae, Gelechiidae, Geometridae, Noctuidae, Tortricidae), Orthoptera (Acrididae, Gryllotalpidae), Thysanoptera (Thripidae) + Acari (Eriophyidae, Tetranychidae) + Crustacea + Diplopoda	Troy Biosciences Inc., USA	Kabaluk and Gazdik (2005), Website[6,8], K. Moran (personal communication), Company brochure
USA	Naturalis L—Home & Garden*	C/OD	Coleoptera (Chrysomelidae, Curculionidae, Scarabaeidae), Hymenoptera (Formicidae), Diptera (Tipulidae), Hemiptera (Lygaeidae, Cercopidae, Cicadellidae, Aleyrodidae, Aphididae, Pseudococcidae, Psyllidae), Lepidoptera (Crambidae, Geometridae, Noctuidae), Orthoptera (Acrididae, Gryllotalpidae), Thysanoptera (Thripidae) + Acari (Tarsonemidae, Tetranychidae) + Crustacea + Diplopoda	Troy Biosciences Inc., USA	Website[8], K. Moran (personal communication), Company brochure
USA	Naturalis-O**	C/OD	Coleoptera (Chrysomelidae, Curculionidae), Hemiptera (Miridae, Cicadellidae, Aleyrodidae, Aphididae, Psyllidae), Lepidoptera, Thysanoptera (Thripidae)	Troy Biosciences Inc., USA	Company brochure
USA	Organigard Emulsifiable Suspension Mycoinsecticide*	C/OD	Coleoptera (Chrysomelidae, Curculionidae, Scarabaeidae), Hemiptera (Miridae, Cicadellidae, Aleyrodidae, Aphididae, Pseudococcidae, Psyllidae), Thysanoptera (Thripidae), Orthoptera (Acrididae, Tettigoniidae), Lepidoptera (Crambidae)	Emerald BioAgriculture Corp., USA (previously: Mycotech Corp., USA)	Hajek et al. (2001), Website[6]

(*continued on next page*)

Table 2 (*continued*)

Country(ies) where undergoing registration, registered or marketed	Trade name[a]	Propagule(s)/ Formulation[b]	Claimed Target(s) (Orders and Families)	Manufacturer	Source(s)[c]
Costa Rica, Panama	Beauvedieca*	C+H/TK	Coleoptera (Curculionidae)	Liga Agricola Industrial de La Caña de Azucar (LAICA), Costa Rica	Website[9]
Costa Rica, Panama	Beauvedieca*	C/NI	Coleoptera (Curculionidae)	Liga Agricola Industrial de La Caña de Azucar (LAICA), Costa Rica	Website[9]
Costa Rica	Nativo 2 SC*	A/NI	Coleoptera (Curculionidae)	Bayer Cropscience S.A., Colombia	W. Solano (personal communication), Website[10]
Guatemala	Bichoxe***	A/NI	Hemiptera (Aleyrodidae)	Produtos Ecológicos, Guatemala	Alves et al. (2003)
Honduras, El Salvador, Guatemala, Jamaica, Nicaragua	Bazam*	CWP	Coleoptera (Chrysomelidae, Curculionidae), Hemiptera (Aleyrodidae, Aphididae), Lepidoptera (Noctuidae, Plutellidae) + Acari (Tetranychidae)	Escuela Agrícola Panamericana, Honduras	Website[9], R. Trabanino (personal communication)
Nicaragua	Mirabiol*	C+H/TK	Coleoptera (Curculionidae)	Union de Cooperativas Agropecuarias (UCA), Nicaragua	Website[9]
Argentina	Bb Vinchuca*	C/OD	Hemiptera (Reduviidae)	Laboratorios Biagro S.A., Argentina	R. Lecuona (personal communication)
Argentina	Bb Moscas*	C/OD	Diptera (Muscidae)	Laboratorios Biagro S.A., Argentina	R. Lecuona (personal communication)
Argentina	Bb Moscas*	C/RB	Diptera (Muscidae)	Laboratorios Biagro S.A., Argentina	R. Lecuona (personal communication)
Brazil	Bovenat*	C+H/TK	Coleoptera (Curculionidae), Hemiptera (Aleyrodidae)	Natural Rural, Brazil	Website[11]
Brazil	Boveril WP ESALQ447*	C+H/TK	Coleoptera (Curculionidae)	Itaforte Industrial de BioProdutos Agro-Florestais Ltda., Brazil	R. Lopes (personal communication)
Brazil	Boveril WP PL63*	C+H/TK	Coleoptera (Curculionidae) + Acari (Tetranychidae)	Itaforte Industrial de BioProdutos Agro-Florestais Ltda., Brazil	A. Ballarotti (personal communication), R. Lopes (personal communication)
Brazil	Boveriol*	C+H/TK	Isoptera (Rhinotermitidae, Termitidae)	Tecnicontrol Ind. e Com. de Produtos Biológicos Ltda., Brazil	Leite et al. (2003b), J. Almeida (personal communication)
Brazil	No trade name*	C+H/TK	Coleoptera (Curculionidae)	Empresa Pernambucana de Pesquisa Agropecuária (IPA), Brazil	E. Marques (personal communication)
Brazil	No trade name**	C+H/TK	Hymenoptera (Formicidae), Siphonaptera (Pulicidae)	Instituto de Biotecnologia Rangel Ltda. (Inbioter), Brazil	D. Rangel (personal communication)
Brazil	No trade name*	C+H/TK	Coleoptera (Curculionidae)	Toyobo do Brasil Ltda., Brazil	J. Almeida (personal communication)
Brazil	Bovemax*	C/OD	Coleoptera (Cerambycidae)	Turfal Ind. Com. Prod. Biol., Brazil	M.S. Leite (personal communication)
Colombia	Ago Biocontrol Bassiana 50***	C/NI	Coleoptera, Diptera, Hemiptera, Lepidoptera	Ago Biocontrol, Colombia	Shah and Goettel (1999)
Colombia	Agronova*	A/NI	Coleoptera (Curculionidae, Scarabaeidae), Lepidoptera (Noctuidae, Nymphalidae, Sphingidae)	Live Systems Technology S.A., Colombia	Website[12]
Colombia	Baubassil*	C/NI	Coleoptera, Hemiptera, Lepidoptera	Productos Biológicos Perkins Ltda, Colombia	Website[13]
Colombia, Dominican Republic	Bauveril*	A/WP	Coleoptera (Curculionidae, Scarabaeidae), Lepidoptera (Castniidae)	Laverlam S.A., Colombia	Alves et al. (2003), Website[14]
Colombia	BioExpert*	A/NI	Hemiptera (Aleyrodidae), Thysanoptera (Thripidae)	Live Systems Technology S.A., Colombia	Website[12]

Table 2 (*continued*)

Country(ies) where undergoing registration, registered or marketed	Trade name[a]	Propagule(s)/ Formulation[b]	Claimed Target(s) (Orders and Families)	Manufacturer	Source(s)[c]
Colombia, Peru, Costa Rica, Dominican Republic, Honduras	Brocaril 50 WP*	A/WP	Coleoptera (Curculionidae)	Laverlam S.A., Colombia	Alves et al. (2003), Website[9,14,15]
Colombia	Brocavec*	NI	NI	Empresa Colombiana de Productos Veterniarios Vecol S.A., Colombia	Website[16]
Colombia	Cebiopest*	NI	NI	Fundacion Centro de Biotecnologia Mariano Ospina Perez, Colombia	Website[16]
Colombia	Conidia***	C/WG	Coleoptera (Curculionidae)	Hoechst Schering AgrEvo, Colombia	Stetter and Lieb (2000), Wraight and Carruthers (1999)
Venezuela	Proecol***	C/NI	Lepidoptera (Noctuidae)	Probioagro S.A., Venezuela	Hajek et al. (2001), Wraight et al. (2001)
Beauveria brongniartii					
Austria, Italy	Melocont-Pilzgerste* (=Beauveria brong)	C+H/TK	Coleoptera (Scarabaeidae)	Kwizda Agro GmbH, Austria/ Agrifutur s.r.l., Italy	Henke et al. (2002), Wraight et al. (2001), H. Strasser (personal communication)
Switzerland	Beauveria brongniartii Myzel*	C+H/TK	Coleoptera (Scarabaeidae)	LBBZ Arenenberg, Switzerland	S. Keller (personal communication)
Switzerland	Beauveria Schweizer*	C+H/TK	Coleoptera (Scarabaeidae)	Eric Schweizer Samen AG, Switzerland	Shah and Pell (2003), Butt and Copping (2000)
Switzerland	Engerlingspilz*	C+H/TK	Coleoptera (Scarabaeidae)	Andermatt Biocontrol AG, Switzerland	Hajek et al. (2001), M. Andermatt (personal communication)
Reunion Island	Betel*	C+H/TK	Coleoptera (Scarabaeidae)	Betel Reunion S.A., Reunion Island (subsidiary of Natural Plant Protection, France)	Hajek et al. (2001), Stetter and Lieb (2000), A. Bonhomme (personal communication)
Japan	Biolisa-Kamikiri*	C+H/TK (fiber band)	Coleptera (Cerambycidae)	Nitto Denko, Japan	Hajek et al. (2001, 2006), Wraight et al. (2001), M. Shimazu (personal communication)
Colombia	Ago Biocontrol Beauveria 50***	A/NI	Coleoptera, Hemiptera, Lepidoptera, Diptera	Ago Biocontrol, Colombia	Shah and Goettel (1999)
Conidiobolus thromboides					
South Africa	No trade name**	C/NI (liquid suspension)	Hemiptera (Aphididae), Thysanoptera (Thripidae)	Mycolab, South Africa	J. Hatting (personal communication)
Colombia, Costa Rica, Honduras	Vektor 25 SL*	C/NI (liquid suspension)	Hemiptera (Aleyrodidae, Ortheziidae)	Laverlam S.A., Colombia	Website[9,14]
Hirsutella thompsonii					
India	MeteHit***	NI	Acari	Plantrich Chemicals & Biofertilizers Ltd, India	Santra (2004)
India	Mycohit*	NI/WP (dusting during wet conditions is possible)	Acari (Eriophyidae)	Hindutan Antibiotics Ltd, India	Copping (2004), Kumar and Singh (2001)
USA	Mycar**	C/WP	Acari (Eriophyidae)	Abbott Laboratories, USA	McCoy (1978, 1996)
Isaria fumosorosea (formerly *Paecilomyces fumosoroseus*)					
Europe (many), Japan	PreFeRal* (=Preferred)	B/WG	Hemiptera (Aleyrodidae)	Biobest n.v., Belgium (under license from Certis, Inc., USA)	Saito (2005), Wraight et al. (2001), Website[17]
India	Priority*	A/WP	Acari (Eriophyidae,Tetranychidae)	T.Stanes & Company Limited, India	Copping (2004), Website[2]

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Table 2 (*continued*)

Country(ies) where undergoing registration, registered or marketed	Trade name[a]	Propagule(s)/ Formulation[b]	Claimed Target(s) (Orders and Families)	Manufacturer	Source(s)[c]
Mexico	Pae-Sin*	C/WP	Hemiptera (Aleyrodidae)	Agrobiologicos del Noroeste S.A. de C.V. (Agrobionsa), Mexico	Wraight et al. (2001), A. Paez (personal communication), Company brochure
Mexico	Pae-Sin*	C/OD	Hemiptera (Aleyrodidae)	Agrobiologicos del Noroeste S.A. de C.V. (Agrobionsa), Mexico	A. Paez (personal communication), Company brochure
Mexico	P. fumosoroseus**	A/NI	Hemiptera (Aleyrodidae)	Centro de Sanidad Vegetal de Guanajuato (CESAVEG), Mexico	Guerra et al. (2001), P. Guerra (personal communication)
USA, Mexico	PFR-97 20% WDG*	B/WG	Hemiptera (Aleyrodidae, Aphididae), Thysanoptera (Thripidae) + Acari (Tetranychidae)	Certis, Inc., USA (previous owner: Thermo Trilogy Corp., USA)	Wraight et al. (2001), Website[6]
Colombia	Ago Biocontrol Paecilomyces 50***	A/NI	Coleoptera + Nematoda	Ago Biocontrol, Colombia	Shah and Goettel (1999)
Colombia	Fumosil*	A/NI	Hemiptera (Aleyrodidae, Aphididae, Pseudococcidae), Thysanoptera (Thripidae)	Productos Biológicos Perkins Ltda, Colombia	Website[13]
Colombia	Successor*	A/NI	Hemiptera (Aleyrodidae, Aphididae), Thysanoptera (Thripidae) + Acari (Tetranychidae)	Live Systems Technology S.A., Colombia	Website[12]
Venezuela	Bemisin***	C/NI	Hemiptera (Aleyrodidae)	Probioagro, Venezuela	Hajek et al. (2001), Wraight et al. (2001)
Isaria sp. (formerly *Paecilomyces* sp.)					
India	PaciHit Rich*	NI (liquid suspension)	Hemiptera (Aleyrodidae), Thysanoptera (Thripidae) + Nematoda	Plantrich Chemicals & Biofertilizers Ltd, India	Website[1]
Lagenidium giganteum					
USA	Laginex AS*	H/SC	Diptera (Culicidae)	AgraQuest, Inc., USA	Scholte et al. (2004), Website[6], R. Riggs (personal communication)
Lecanicillium longisporum (formerly *Verticillium lecanii*)					
Finland, Switzerland, UK, Japan	Vertalec*	B/WP	Hemiptera (Aphididae)	Koppert Biological Systems, Netherlands (previously: Tate and Lyle, UK)	Website[18], W. Ravensberg (personal communication)
Brazil	Vertirril WP 1300*	C+H/TK	Hemiptera (Aleyrodidae, Ortheziidae)	Itaforte Industrial de BioProdutos Agro-Florestais Ltda., Brazil	A. Ballarotti (personal communication), R. Lopes (personal communication)
Lecanicillium muscarium (formerly *V. lecanii*)					
Netherlands, Denmark, Finland, France, Italy, Switzerland, UK, Turkey, Japan,	Mycotal*	C/WP	Hemiptera (Aleyrodidae), Thysanoptera (Thripidae)	Koppert Biological Systems, Netherlands (previously: Tate and Lyle, UK)	Website[18], W. Ravensberg (personal communication)
Russia	Verticillin*	B/WP	Hemiptera (Aleyrodidae, Aphididae) + Acari (Tetranychidae)	Biodron, Russia	Shternshis (2004), M. Shternshis (personal communication)
Russia	Verticillin*	B/NI (liquid suspension)	Hemiptera (Aleyrodidae, Aphididae) + Acari (Tetranychidae)	Biodron, Russia	Shternshis (2004), M. Shternshis (personal communication)
Lecanicillium sp. (formerly *V. lecanii*)					
Spain	Trichovert*	A/NI	Not informed	Trichodex S.A., Spain	Website[1]
Switzerland	MicroGermin Plus*	H/WP	Hemiptera (Aleyrodidae, Aphididae), Thysanoptera (Thripidae) + Acari (Tetranychidae)	Omya (Schweiz) AG, Switzerland	S. Keller (personal communication)

Table 2 (*continued*)

Country(ies) where undergoing registration, registered or marketed	Trade name[a]	Propagule(s)/ Formulation[b]	Claimed Target(s) (Orders and Families)	Manufacturer	Source(s)[c]
India	Bio-Catch*	A/WP	Hemiptera (Aleyrodidae, Aphididae, Pseudococcidae)	T.Stanes & Company Limited, India	Copping (2004), Website[2]
India	Biovert Rich*	A/NI (powder)	"Insects" + Nematoda	Plantrich Chemicals & Biofertilizers Ltd, India	Website[1]
India	Mealikil*	A/WP	Hemiptera: Sternorrhyncha ("scales") + others (not specified)	Agri Life, India	Copping (2004), Website[3]
Mexico	Verti-Sin*	C/OD	Hemiptera (Aphididae), Thysanoptera (Thripidae)	Agrobiologicos del Noroeste S.A. de C.V. (Agrobionsa), Mexico	A. Paez (personal communication), Company brochure
Honduras, El Salvador, Guatemala, Jamaica, Nicaragua	Verzam*	C/NI	Hemiptera (Aleyrodidae, Aphididae), Thysanoptera (Thripidae) + Acari (Tetranychidae)	Escuela Agrícola Panamericana, Honduras	Website[9], R. Trabanino (personal communication)
Brazil	No trade name*	C/OD	Hemiptera (Aphididae)	Turfal Ind. Com. Prod. Biol., Brazil	M.S. Leite (personal communication)
Brazil	Vertinat*	C+H/TK	Hemiptera (Aleyrodidae, Ortheziidae)	Natural Rural, Brazil	Website[11]
Colombia	Ago Biocontrol Verticillium 50***	A/NI	Hemiptera, Diptera	Ago Biocontrol, Colombia	Shah and Goettel (1999)
Colombia, Peru, Costa Rica, Honduras	Vertisol 50 WP*	A/WP	Hemiptera (Aleyrodidae)	Laverlam S.A., Colombia	Website[9,14,15]
Metarhizium anisopliae					
Austria, Italy	Granmet-P*	C+H/TK	Coleoptera (Scarabaeidae, Curculionidae, Nitidulidae)	Kwizda Agro GmbH, Austria/ Agrifutur s.r.l., Italy	H. Strasser (personal communication)
Germany, Switzerland	BIO 1020**	H/GR (more specifically, a Fine Granule-FG)	Coleoptera (Curculionidae)	Bayer AG, Germany	Hajek et al. (2001), Feng et al. (1994), D. Roberts (personal communication)
Spain	Trichomet*	C/NI	Not informed	Trichodex S.A., Spain	Website[1]
Switzerland	BIO 1020*	H/GR	Coleoptera (Curculionidae)	Intrachem Bio SA, Italy	S. Keller (personal communication)
Switzerland	Metarhizium Andermatt**	C+H/TK	Coleoptera (Scarabaeidae)	Andermatt Biocontrol AG, Switzerland	Hajek et al. (2001), M. Andermatt (personal communication)
Switzerland	Metarhizium Schweizer*	C+H/TK	Coleoptera (Scarabaeidae)	Eric Schweizer Samen AG, Switzerland	Hajek et al. (2001), Wraight et al. (2001), S. Keller (personal communication)
India	Bio-Magic*	A/WP (also applied undiluted into soil for control of grubs and weevils)	Coleoptera (Curculionidae, Scarabaeidae), Hemiptera (Cercopidae) + others ("plant hoppers")	T.Stanes & Company Limited, India	Website[2]
India	Biomet Rich*	A/NI (liquid suspension)	Coleoptera, Isoptera	Plantrich Chemicals & Biofertilizers Ltd, India	Website[1]
India	Pacer*	A/WP	Isoptera	Agri Life, India	Copping (2004), Website[3]
Australia	BioCane Granules Biological Insecticide*	C+H/TK	Coleoptera (Scarabaeidae)	Becker Underwood Inc., USA—Australian division (previously: Bio-Care Technology Pty Ltd)	Samson et al. (2005), Milner et al. (2002), Website[19]

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Table 2 (*continued*)

Country(ies) where undergoing registration, registered or marketed	Trade name[a]	Propagule(s)/ Formulation[b]	Claimed Target(s) (Orders and Families)	Manufacturer	Source(s)[c]
Australia	Chafer Guard Granules* (= Biogreen)	C+H/TK	Coleoptera (Scarabaeidae)	Becker Underwood Inc., USA—Australian division (under licence from Dept. Primary Industry and Adelaide Research and Innovation Pty Limited, Australia)	Website[19]
Mexico	Fitosan-M*	A/NI	Coleoptera (Scarabaeidae), Orthoptera	Centro de Sanidad Vegetal de Guanajuato (CESAVEG), Mexico	Guerra et al. (2001), P. Guerra (personal communication)
Mexico	Meta-Sin*	C/WP	Coleoptera (Curculionidae, Scarabaeidae), Hemiptera (Cercopidae), Orthoptera	Agrobiologicos del Noroeste S.A. de C.V. (Agrobionsa), Mexico	Hajek et al. (2001), A. Paez (personal communication), Company brochure
Mexico	Meta-Sin*	C/OD	Coleoptera (Curculionidae, Scarabaeidae), Hemiptera (Cercopidae), Orthoptera	Agrobiologicos del Noroeste S.A. de C.V. (Agrobionsa), Mexico	A. Paez (personal communication), Company brochure
USA, Mexico	Bio-Blast Biological Termiticide*	C/TC	Isoptera (Kalotermitidae, Rhinotermitidae, Termopsidae)	EcoScience Corporation, USA	Wraight and Carruthers (1999), Rath (1995), Website[6], Company brochure
USA	Bio-Path Cockroach Control Chamber**	C/RB	Blattodea (Blattellidae, Blattidae)	EcoScience Corporation, USA	Evans (2003), Hajek et al. (2001), Gunner et al. (1995), J. Lord (personal communication)
USA	Taenure Granular Bioinsecticide*	C/GR	Coleoptera (Curculionidae, Scarabaeidae), Diptera (Ephydridae, Mycetophilidae, Sciaridae, Tipulidae), Thysanoptera (Thripidae)	Novozymes Biologicals Inc., USA (previously: Earth BioSciences; (Taensa Co., USA)	Website[6], Company brochure
USA	Taerain**	C/OD	Hemiptera (Aleyrodidae), Thysanoptera (Thripidae) + Acari (Tetranychidae)	Earth BioSciences Inc., USA	Company brochure
USA	Tick-EX EC*	C/OD	Acari (Ixodidae) + Coleoptera (Scarabaeidae)	Novozymes Biologicals Inc., USA (previously: Earth BioSciences; Taensa Co., USA)	Website[6], Company brochure
USA	Tick-EX G*	C/GR	Acari + Coleoptera (Scarabaeidae)	Novozymes Biologicals Inc., USA (previously: Earth BioSciences; Taensa Co., USA)	Website[6]
Costa Rica, Panama	Metadieca*	C+H/TK	Hemiptera (Cercopidae)	Liga Agricola Industrial de La Caña de Azucar (LAICA), Costa Rica	Website[9]
Costa Rica, Panama	Metadieca*	C/TC	Hemiptera (Cercopidae)	Liga Agricola Industrial de La Caña de Azucar (LAICA), Costa Rica	Website[9]
Costa Rica	Technogreen Metarhizium 35 SL*	A/NI (liquid suspension)	Not informed	Biolaboratorios de Centroamerica S.A. (Biolab), Costa Rica	Website[10]
Guatemala	Salivase***	A/NI	Hemiptera (Cercopidae)	Produtos Ecológicos, Guatemala	Alves et al. (2003)
Honduras, El Salvador, Guatemala, Jamaica, Nicaragua	Metazam*	C/WP	Hemiptera (Cercopidae), Lepidoptera (Crambidae) + Acari (Ixodidae)	Escuela Agrícola Panamericana, Honduras	R. Trabanino (personal communication)
Nicaragua	Metarhisa WP*	C/WP	Coleoptera (Curculionidae), Hemiptera (Cercopidae), Lepidoptera (Crambidae)	Nicaragua Sugar Estates Limited, Nicaragua	Website[9]
Brazil	BioCerto para Cigarrinhas*	C/OD	Hemiptera (Cercopidae)	Biocerto Ind. Com. Prod. Agrop. Ltda, Brazil	J. Falcão (personal communication)
Brazil	BioCerto PM*	C/TC	Hemiptera (Cercopidae)	Biocerto Ind. Com. Prod. Agrop. Ltda, Brazil	J. Falcão (personal communication)

Table 2 (*continued*)

Country(ies) where undergoing registration, registered or marketed	Trade name[a]	Propagule(s)/ Formulation[b]	Claimed Target(s) (Orders and Families)	Manufacturer	Source(s)[c]
Brazil	Biocontrol**	C/NI	Hemiptera (Cercopidae)	Agroceres, Brazil	Leite et al. (2003b), S. Alves (personal communication)
Brazil	Biomax**	C/WP	Hemiptera (Cercopidae)	Labormax Produtos Químicos Ind. e Com. Ltda., Brazil	R. Pereira (personal communication)
Brazil, Panama	Biotech*	C+H/TK	Hemiptera (Cercopidae)	Biotech, Brazil	Leite et al. (2003b), E. Marques (personal communication)
Brazil	Conbio**	C+H/TK	Hemiptera (Cercopidae)	Equilíbrio Controle Biológico Ltda, Brazil	A. Batista Filho (personal communication)
Brazil	Metabiol*	C+H/TK	Hemiptera (Cercopidae)	Tecnicontrol Ind. e Com. de Produtos Biológicos Ltda., Brazil	Leite et al. (2003b)
Brazil	Metanat*	C/OD	Hemiptera (Cercopidae, Aphididae)	Natural Rural, Brazil	Website[11]
Brazil	Metanat*	C+H/TK	Hemiptera (Cercopidae, Aphididae)	Natural Rural, Brazil	Website[11]
Brazil	Metaquino**	C+H/TK	Hemiptera (Cercopidae)	Com. Exec. Def. Fit. Lav. Can. PE (CODECAP), Brazil	Aquino et al. (1975)
Brazil	Metarril WP E9*	C+H/TK	Hemiptera (Cercopidae)	Itaforte Industrial de BioProdutos Agro-Florestais Ltda., Brazil	R. Lopes (personal communication)
Brazil	Metarril SC 1037*	C/OD	Hemiptera (Cercopidae) + Acari (Ixodidae)	Itaforte Industrial de BioProdutos Agro-Florestais Ltda., Brazil	R. Lopes (personal communication)
Brazil	Metarriz*	C+H/TK	Hemiptera (Cercopidae)	Biocontrol Sistemas de Controle Biológico, Brazil	J. Almeida (personal communication)
Brazil	Methamax*	C/OD	Hemiptera (Cercopidae)	Turfal Ind. Com. Prod. Biol., Brazil	M.S. Leite (personal communication)
Brazil	Methavida*	C+H/TK	Hemiptera (Cercopidae)	Methavida Controle Biológico Agrícola, Brazil	J. Almeida (personal communication)
Brazil	No trade name*	C+H/TK	Hemiptera (Cercopidae)	Bioagro Controle Biológico, Brazil	E. Marques (personal communication)
Brazil	No trade name*	C+H/TK	Hemiptera (Cercopidae)	Biocana Braz e Costa Ind. e Com. de Produtos Biológicos, Brazil	J. Almeida (personal communication)
Brazil	No trade name**	C/NI	Hemiptera (Cercopidae)	BTA, Brazil	Leite et al. (2003b)
Brazil	No trade name*	C+H/TK	Hemiptera (Cercopidae)	Empresa Mato-Grossense de Pesquisa, Assistência e Extensão Rural S/A (EMPAER), Brazil	M. Santaella (personal communication)
Brazil	No trade name*	C+H/TK	Hemiptera (Cercopidae)	Empresa Pernambucana de Pesquisa Agropecuária (IPA), Brazil	E. Marques (personal communication)
Brazil	No trade name*	C+H/TK	Hemiptera (Cercopidae)	Empresa de Pesquisa Agropecuária do Estado do Rio de Janeiro (PESAGRO), Brazil	S. Alves (personal communication)
Brazil	No trade name*	C+H/TK	Hemiptera (Cercopidae)	Fitossan Assistência Fitossanitária e Controle Biológico Ltda., Brazil	J. Santos (personal communication)
Brazil	No trade name*	C+H/TK	Hemiptera (Cercopidae)	Fundação Agro-ambiental da Amazônia (FUNAM), Brazil	V. Rocha (personal communication)
Brazil	No trade name*	C+H/TK	Hemiptera (Cercopidae)	Instituto Biológico, Brazil	J. Almeida (personal communication)
Brazil	No trade name**	C+H/TK	Hymenoptera (Formicidae), Siphonaptera (Pulicidae)	Instituto de Biotecnologia Rangel Ltda. (Inbioter), Brazil	D. Rangel (personal communication)
Brazil	No trade name*	C+H/TK	Hemiptera (Cercopidae)	Toyobo do Brasil Ltda., Brazil	J. Almeida (personal communication)
Colombia	Ago Biocontrol Metarhizium 50***	A/NI	Coleoptera, Hemiptera, Lepidoptera, Orthoptera	Ago Biocontrol, Colombia	Shah and Goettel (1999)

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Table 2 (*continued*)

Country(ies) where undergoing registration, registered or marketed	Trade name[a]	Propagule(s)/ Formulation[b]	Claimed Target(s) (Orders and Families)	Manufacturer	Source(s)[c]
Colombia	DeepGreen*	A/NI	Coleoptera (Scarabaeidae), Hemiptera (Miridae, Cicadellidae)	Live Systems Technology S.A., Colombia	Website[12]
Colombia, Costa Rica, Honduras, Nicaragua	Destruxin* (=Dextruxin 50 WP)	A/WP	Coleoptera (Curculionidae, Scarabaeidae), Hemiptera (Miridae, Cercopidae, Delphacidae), Lepidoptera (Noctuidae)	Laverlam S.A., Colombia	Website[9,14]
Colombia	Metaril*	C/NI	Coleoptera (Curculiionidae, Scarabaeidae), Hemiptera (Miridae, Pentatomidae, Cercopidae, Delphacidae), Lepidoptera (Noctuidae)	Productos Biológicos Perkins Ltda, Colombia	Website[13]
Venezuela	Cobican***	C/NI	Coleoptera (Scarabaeidae), Hemiptera (Cercopidae, Aphididae)	Probioagro S.A., Venezuela	Alves et al. (2003), Wraight et al. (2001)
Venezuela	Metabiol***	A/NI	Hemiptera (Cercopidae)	Empresa Prave Agrobioténica S.A., Venezuela	Website[20]
Metarhizium anisopliae var. *acridum*					
Mozambique, Namibia, Tanzania, South Africa, Sudan, Zambia	Green Muscle OF*	C/OF	Orthoptera (Acrididae, Pyrgomorphidae)	Biological Control Products SA (Pty) Ltd, South Africa (under license from CABI, UK)	Pettit and Jenkins (2005), Bateman (1997), Website[2]
Australia	Green Guard ULV*	C/OF	Orthoptera (Acrididae)	Becker Underwood Inc., USA—Australian division (under licence from CSIRO, Australia)	Milner and Hunter (2001), Website[19], P. Melville (personal communication)
Australia	Green Guard SC*	C/TC (dry spores, surfactant solution and emulsifiable oil are sold together, but not mixed)	Orthoptera (Acrididae)	Becker Underwood Inc., USA—Australian division (under licence from CSIRO, Australia)	Website[19]
Nomuraea rileyi					
Colombia	Ago Biocontrol Nomuraea 50***	A/NI	Lepidoptera	Ago Biocontrol, Colombia	Shah and Goettel (1999)
"*Sporothrix insectorum*"					
Brazil	No trade name**	C+H/TK	Hemiptera (Tingidae)	Estação de Aviso Fitossanitário de São José do Rio Claro, Brazil	M.A. Leite (personal communication)
Brazil	No trade name*	S+B+H/TK (liquid substrate)	Hemiptera (Tingidae)	Instituto Biológico, Brazil	Leite et al. (2003a), J. Almeida (personal communication)
Brazil	Sporothrix ES*	C/OD	Hemiptera (Tingidae)	Biocerto Ind. Com. Prod. Agrop. Ltda, Brazil	J. Falcão (personal communication)
Mix: *B. bassiana*, *M. anisopliae*, *I. fumosorosea*					
Mexico	Tri-Sin*	C/WP	Hemiptera (Psyllidae)	Agrobiologicos del Noroeste S.A. de C.V. (Agrobionsa), Mexico	A. Paez (personal communication), Company brochure
Mexico	Tri-Sin*	C/OD	Hemiptera (Psyllidae)	Agrobiologicos del Noroeste S.A. de C.V. (Agrobionsa), Mexico	A. Paez (personal communication), Company brochure
Mix: *B. bassiana*, *M. anisopliae* + *Paecilomyces lilacinus*					
Colombia	Fungio WP*	NI	NI	Orius Biotecnología, Colombia	Website[21]

Table 2 (*continued*)

Country(ies) where undergoing registration, registered or marketed	Trade name[a]	Propagule(s)/ Formulation[b]	Claimed Target(s) (Orders and Families)	Manufacturer	Source(s)[c]
Colombia, Ecuador, Chile, Peru, Panama	Micosplag[*]	C/WP	Coleoptera (Chrysomelidae, Curculionidae, Scarabaeidae), Hemiptera (Lygaeidae, Miridae, Pentatomidae, Tingidae, Cercopidae, Delphacidae), Lepidoptera (Noctuidae, Nymphalidae, Crambidae) + Nematoda	Orius Biotecnología, Colombia	Website[15,21], M. Higuera (personal communication)
Mix: *B. bassiana*, *M. anisopliae*, *N. rileyi*, *I. fumosorosea* + *Bacillus thuringiensis*					
Colombia	Micobiol Completo[***]	A/NI	Coleoptera, Hemiptera, Lepidoptera, Diptera + Acari	NI	Alves et al. (2003)
Mix: *B. bassiana*, *H. thompsonii*, *Lecanicillium* sp., *M. anisopliae*, *N. rileyi*, *I. fumosorosea* + *P. lilacinus*					
Colombia	Micobiol HE[***]	A/NI	Coleoptera, Diptera, Hemiptera, Lepidoptera + Acari + Nematoda	NI	Alves et al. (2003)
Mix (?): *Lecanicillium* spp. (formerly *V. lecanii*)					
Scandinavia	MicroGermin[**]	A/WP	Hemiptera (Aleyrodidae, Aphididae)	Christian Hansen BioSystems, Denmark	Butt et al. (1999), Helyer et al. (1992), W. Ravensberg (personal communication)

[a] Availability of product is informed as follows: [*]active, [**]inactive, and [***]current status could not be determined (see Table 1 for additional information).

[b] Categories adopted for propagule types of developed products: H, hyphae (mycelia); A, asexual spores (type not informed); C, aerial conidia; S, submerged conidia; B, blastospores (= hyphal bodies); NI, not informed by consulted sources.

[c] Websites consulted:

[1] AMC Chemical and Trichodex (http://www.amcchemical.com/).
[2] Biological Control Products SA (Pty) Ltd (http://www.biocontrol.co.za).
[3] Plantrich Chemicals & Biofertilizers Ltd. (http://www.indiamart.com/biofertilizers/).
[4] T.Stanes & Company Limited (http://www.tstanes.com).
[5] Agri Life (http://www.somphyto.com).
[6] EPA—Environmental Protection Agency (http://www.epa.gov/oppbppd1/biopesticides/ingredients/).
[7] Laverlam International Corporation (http://www.laverlamintl.com/).
[8] Troy Biosciences, Inc. (http://www.troybiosciences.com/).
[9] Bioplaguicidas.Org (http://www.bioplaguicidas.org/) (in Spanish).
[10] Servicio Fitosanitario del Estado—Costa Rica, Potecnet (http://www.protecnet.go.cr/InsumoSys/Principal.htm) (in Spanish).
[11] Natural Rural (http://www.naturalrural.com.br/) (in Portuguese).
[12] Live Systems Technology S.A. (http://lstsa.com/).
[13] Productos Biológicos Perkins Ltda (http://www.perkinsltda.com.co/) (in Spanish).
[14] Laverlam S.A. (www.laverlam.com.co/espanol/portada.htm) (in Spanish).
[15] Servicio Nacional de Sanidade Agraria (http://www.senasa.gob.pe) (in Spanish).
[16] Rede de Información y Comunicación Estratégica del Sector Agropecuario—AGRONET (http://www.agronet.gov.cl) (in Spanish).
[17] Biobest n.v. (http://www.biobest.be/).
[18] Koppert Biological Systems (www.koppert.nl/).
[19] Becker Underwood Pty Ltd (http://www.beckerunderwood.com/australia/).
[20] http://www.plagas-agricolas.info.ve/ (in Spanish).
[21] Orius Biotecnología (http://www.Oriusbiotecnologia.com/site/) (in Spanish).

1979). Although most products are based on specific types of propagules (Section 2.1), the end product may contain small or even substantial amounts of other propagule types. Products based on aerial conidia may contain hyphae, and vice-versa, and mycoinsecticides produced through liquid fermentation may present a mix of submerged conidia, blastospores and hyphae (Leite et al., 2003a). The exact propagule composition of biopesticide products is rarely stated by manufacturers, and, in some cases, the specific propagule comprising the active ingredient is not indicated. For many of these products, the active ingredient is quantified in terms of colony forming units. Thus, in this listing we report only what we were able to identify from product claims and descriptions as the predominant propagule type. For six products, no identification of propagule type was possible. Based on the available information, we determined that a significant proportion of products (25.7%, most of these classified as technical concentrates) contain both asexual spores and hyphae. However, 67.5% of all products are described as

being based exclusively on asexual spores, with aerial conidia being the most common among all products (41.2%). Only 4.1% of listed products are claimed to contain only blastospores, whereas this kind of propagule is also present in two other products, one including submerged conidia and one including submerged conidia and hyphae. No products have been reported as containing only submerged conidia, and those based exclusively on hyphae account for only 2.3% of all products. The type of asexual spore could not be determined for 22.2% of products.

Formulation types could not be determined for 25.7% of all listed products, and despite conflicting data and lack of standardization among different sources, two technical products (TC and TK) and nine different formulation types were identified. The most common types were technical concentrates in the form of fungus-colonized substrates (26.3%), wettable powders (20.5%), and oil dispersions (15.2%). The remaining types include granules (2.9%), technical materials (2.9%), baits (1.8%), water dispersible granules (1.8%), oil miscible flowable concentrates (1.2%), ULV suspensions (0.6%), suspension concentrates (0.6%), and contact powders (0.6%).

As indicated previously, assigning a formulation type to a product is not a straightforward step. Formulation definitions developed for chemical pesticides often are not precisely applicable to biopesticides. Revisions in the international code to accommodate current microbial formulation designations are needed. Also, there is a great deal of overlap among formulation definitions, and a single product may fall into more than one category. There is, therefore, a certain amount of subjectivity associated with selection of the proper code, and there are many circumstances in which designations adopted in this paper do not match those used in previous publications or by manufacturers.

Among listed products, at least 160 (93.6%) are claimed to have activity against insects, and 28 (16.4%) against acarines. Nematodes (2.9%), crustaceans (1.2%), and centipedes (1.2%) also are among the claimed target hosts, while targets for 4.7% of products could not be determined. The sum of the above percentages is substantially greater than 100% due to the fact that most products are indicated as controlling pests in more than one order and usually multiple species within an order (data not shown). Targets are distributed among 10 insect orders: Hemiptera (59.6%), Coleoptera (40.9%), Lepidoptera (17.5%), Thysanoptera (14.6%), Orthoptera (9.4%), Diptera (7.0%), Hymenoptera (2.9%), Isoptera (2.3%), Siphonaptera (1.2%), and Blattodea (0.6%). The listed products are claimed to control targets in at least 48 insect families, with insects in the families Aleyrodidae, Curculionidae (including Scolytinae), Cercopidae, Scarabaeidae, Aphididae, and Thripidae being among the most common targets (Table 3). Among mycoacaricides, only three products, all based on *H. thompsonii*, were developed specifically for control of acarines. Target acarines are from at least four families, but predominantly focused on Tetranychidae.

Out of 129 products currently in the "active" category (registered, undergoing registration or available), over 90% were developed for inundation microbial control, while less than 10% were developed exclusively for inoculation control strategies (as defined by Eilenberg et al., 2001). The latter strategy is based on mycoinsecticides with high mycelial concentration, for example formulated products based solely on hyphae, or fungus-colonized substrates for control of soil-inhabiting beetles.

Historically, countries in Asia, Latin America, and Eastern Europe have accounted for the greatest use of fungal pathogens. As reviewed by Feng et al. (1994), in the 1980s approximately 0.8–1.3 million hectares of forests in China were treated annually with *B. bassiana* for control of numerous pests; however, this use was largely government supported (noncommercial) and has declined markedly in recent years (Feng, 2003). Commercial production of mycopesticides is only beginning in China; launches by private companies of formulated products for management of grasshoppers and tea leafhoppers is anticipated (M.-G. Feng, Zhejiang University, China, personal communication). There also have been high levels of noncommercial production of mycoinsecticides by grower cooperatives in Brazil during the 1970s and 1980s (Alves, 1998), by government laboratories in several Eastern European countries (especially Russia, Poland and Czechoslovakia) during the same time period (Lipa, 1985; Feng et al., 1994), and by government laboratories in Cuba since the 1990s (Rosset, 1997; Vega, 2005).

Products developed by South American companies and institutions represent 42.7% of all listed (commercial) products, followed by North America (20.5%), Europe and Asia (12.3% each), Central America (7.0%), Africa (2.9%), and Oceania (2.3%). The data suggest that the largest current program using entomopathogenic fungi is based on *M. anisopliae* application for control of spittlebugs in sugarcane fields and pastures of South and Central America. Among the 58 listed products based on *M. anisopliae*, 37 (63.8%) are claimed to be active against cercopids, and over 90% of these are currently available in South and Central America. In Brazil, *M. anisopliae* is used to control a complex of spittlebugs, including *Mahanarva fimbriolata* (Stål) and *Mahanarva posticata* (Stål) in sugarcane fields, and *M. fimbriolata*, *Deois flavopicta* (Stål) and *Notozulia entreriana* (Berg) in pastures (Alves, 1998; Faria and Magalhães, 2001). In a single sugarcane operation, this fungus is annually applied on over 60,000 hectares for control of *M. fimbriolata* (J.E.M. de Almeida, Instituto Biológico, Brazil, personal communication). Other impressive numbers relate to the worldwide use of *M. anisopliae* for scarab control, and *B. bassiana* for control of weevils, whiteflies, scarabs, thrips, and aphids, each with at least 10 products currently in the "active" category.

In the literature there is a great deal of incomplete, inconsistent and even conflicting information regarding developed mycopesticides. Other difficulties in assembling an accurate list of products are related to incomplete infor-

Table 3
Number of mycopesticides and mycoacaricides per target orders and families

Orders and families	Fungal agents[a]																	
	Aa	Bb	Bbr	Ct	Ht	If	Isp	Lg	Ll	Lm	Lsp	Ma	Mac	Nr	Si	Mix	Total	%[b]
Blattodea												1					1	0.6
Blattellidae												1					1	0.6
Blattidae												1					1	0.6
Coleoptera		37	7			1						22				3	70	40.9
Cerambycidae		2	1														3	1.8
Chrysomelidae		10														1	11	6.4
Curculionidae		31										10				1	42	24.6
Scarabaeidae		15	5									16				1	37	21.6
Nitidulidae												1					1	0.6
Family—Not informed			1			1						2				2	6	3.5
Diptera		6	1					1			1	1				2	12	7.0
Culicidae								1									1	0.6
Ephydridae		1										1					2	1.2
Muscidae		3															3	1.8
Mycetophilidae		1										1					2	1.2
Sciaridae		1										1					2	1.2
Tipulidae		2										1					3	1.8
Family—Not informed		1	1								1					2	5	2.9
Hemiptera	1	25	1	2		8	1		2	3	10	40			3	6	102	59.6
Heteroptera: Lygaeidae		2														1	3	1.8
Heteroptera: Miridae		8										3				1	12	7.0
Heteroptera: Pentatomidae												1				1	2	1.2
Heteroptera: Reduviidae		1															1	0.6
Heteroptera: Tingidae															3	1	4	2.3
Auchenorrhyncha: Cercopidae		2										37				1	40	23.4
Auchenorrhyncha:: Cicadellidae		9										1					10	5.8
Auchenorrhyncha: Delphacidae		1										2				1	4	2.3
Auchenorrhyncha: Fulgoridae		5															5	2.9
Sternorrhyncha: Aleyrodidae	1	20		1		8	1		1	3	5	1				1	42	24.6
Sternorrhyncha: Aphididae		12		1		3			1	2	5	3				1	28	16.4
Sternorrhyncha: Ortheziidae				1					1		1						3	1.8
Sternorrhyncha: Pseudococcidae		8				1					1						10	5.8
Sternorrhyncha: Psyllidae		9														2	11	6.4
Family—Not informed		2	1								2	1				2	8	4.7
Hymenoptera		4										1					5	2.9
Formicidae		4										1					5	2.9
Isoptera		1										3					4	2.3
Kalotermitidae												1					1	0.6
Rhinotermitidae		1										1					2	1.2
Termitidae		1															1	0.6
Termopsidae												1					1	0.6
Family—Not informed												2					2	1.2
Lepidoptera		20	1									5		1		3	30	17.5
Castniidae		2															2	1.2
Crambidae		9										2				1	12	7.0
Gelechiidae		1															1	0.6
Geometridae		2															2	1.2
Noctuidae		7										2				1	10	5.8
Nymphalidae		1														1	2	1.2
Pieridae		2															2	1.2
Plutellidae		3															3	1.8
Sphingidae		1															1	0.6
Tortricidae		2															2	1.2
Family—Not informed		4	1									1		1		2	9	5.3
Orthoptera		9										4	3				16	9.4
Acrididae		8											3				11	6.4
Gryllotalpidae		2															2	1.2
Pyrgomorphidae													1				1	0.6

(*continued on next page*)

Table 3 (*continued*)

Orders and families	Fungal agents[a]																	
	Aa	Bb	Bbr	Ct	Ht	If	Isp	Lg	Ll	Lm	Lsp	Ma	Mac	Nr	Si	Mix	Total	%[b]
Tettigoniidae		6															6	3.5
Family—Not informed		1										4					5	2.9
Siphonaptera		1										1					2	1.2
Pulicidae		1										1					2	1.2
Thysanoptera		14		1		3	1			1	3	2				1	25	14.6
Thripidae		14		1		3	1			1	3	2					25	14.6
Acari		11			3	3				2	2	5				2	28	16.4
Eriophyidae		1			2	1											4	2.3
Ixodidae												3					3	1.8
Tarsonemidae		1															1	0.6
Tetranychidae		9				3				2	2	1					17	9.9
Family—Not informed					1							1				2	4	2.3
Order(s) not informed		3									2	2				1	8	4.7

[a] Aa, *Aschersonia aleyrodis*; Bb, *Beauveria bassiana*; Bbr, *B. brongniartii*; Ct, *Conidiobolus thromboides*; Ht, *Hirsutella thompsonii*; If, I*saria fumosorosea*; Isp, *Isaria* sp.; Lg, *Lagenidium giganteum*; Ll, *Lecanicillium longisporum*; Lm, *L. muscarium*; Lsp, *Lecanicillium* sp.; Ma, *Metarhizium anisopliae*; Mac, *M. anisopliae* var. *acridum*; Nr, *Nomuraea rileyi*; Si, *Sporothrix insectorum*; Mix, mixture of two or more species.

[b] Percentages calculated by dividing the number of products per order/family by the total number of products (171).

mation presented on product labels or in product descriptions (when available), lack of up-to-date information (especially following corporate mergers), information in only one language, etc. Despite its imperfections, the list of products presented in this work represents a database that could be updated periodically, providing the scientific community with a valuable source of state-of-the-art information on fungus-based insecticides and acaricides.

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