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Management of coleopteran pests through entomopathogenic nematodes

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Abstract
Beetles and weevils cause major damage to many agricultural and horticultural crops. Chemicals are recommended for controlling of the coleopteran pests. One of the promising biocontrol agent is the entomopathogenic nematodes. This review finds the work done in several countries for management of these insect pests.

Keywords: coleopteran insect pests, biocontrol agent, entomopathogenic nematodes, beetles, weevils

Introduction
Beetles comprise forty percent of the insect kingdom, and come in a wide variety of shapes, colors and sizes. In general, all have hard, opaque wing covers that meet in a straight line down the middle of their backs, a characteristic that gives them an armored appearance. Of primary importance are the leaf beetles (Chrysomelidae) and the weevils and their relatives (Curculionoidea). Leaf-beetle larvae feed on leaves, stems, or roots of plants and most adults chew leaves. Various species of weevil larvae or adults have been found feeding on almost every plant part; especially numerous are species that bore into trunks, stems, and seeds.

Habitat of Coleopteran Insects
Beetles are found in almost any habitat occupied by insects and feed on a variety of plant and animal materials. Many are predatory; some are scavengers; many are plant feeders (phytophagous); others feed on fungi; and a few are parasitic on other organisms. Beetles may live beneath the ground, in water, or as commensals in the nests of social insects such as ants and termites. Plant-feeding species may eat foliage, bore in wood or fruit, and attack roots or blossoms; any part of a plant may be a food source for some type of beetle. Many beetles eat stored plant or animal products, including various types of foods and clothing. Weevils also are diverse in habits. Many larvae bore into solid wood of living or dead trees and stumps; some feed on or in roots or in stems of semi woody plants; and others feed in seeds, pods, grain, meal, fruits, nuts, and other parts of plants; some are hidden inside the plants. Most adults are able to fly. Some species, which develop in rotting stumps, soil, or palm trunks, make a rough cocoon from frass.

Some beetles undergo hyper metamorphosis, in which they have different larval types in different instars (the stages between molts). The early larval stages usually are active, and the later stages are parasitic on other organisms. Numerous species of beetles inflict damage to flowers and garden crops, both in their larval and adult stages. They do this by eating leaves, stalks and flowers, and sometimes plant roots. Their snout-nosed cousins, weevils and curculios, primarily inflict damage by boring into stems, flower buds and fruit.

Entomopathogenic Nematodes (Epns)
Entomopathogenic nematodes (EPNs) are important biological control agents for a variety of economically important pests (Grewal *et al*., 2005) [81] and particularly suited to controlling soil pests (Klein, 1990) [111]. They have potential for use in augmentative and/or inundative biological control (Parkman & Smart, 1996) [146], they can be mass produced *in vitro* (Ehlers, 2001). Entomopathogenic nematodes (EPNs) in the families Heterorhabditidae and Steinernematidae are obligate insect parasites (Kaya and Gaugler, 1993) [36] that have been extensively used in biological pest control (Georgis *et al*., 2006) [74]. These nematodes have evolved a mutualistic association with bacteria in the genera *Xenorhabdus* and *Photorhabdus*. *Photorhabdus* is associated with *Heterorhabditis* and is carried in the intestine

(Birdand Akhurst, 1983; Silva *et al*., 2002) [29, 193]. *Xenorhabdus* is associated with *Steinernema* and confined to a specific vesicle within the intestine of the infective juveniles (IJs). Nematodes locate their potential host by following insect cues (Lewis *et al*., 2006) [124]. After IJs locate either insect, they infect the host through either orifice such as the anus, mouth, and spiracles or by penetrating the cuticle. Once IJs enter the host, they shed their outer cuticle (Sicard *et al*., 2004) [192] and begin ingesting hemolymph, which triggers the release of symbionts by defecation or regurgitation (Martens and Goodrich-Blair, 2005) [135]. The developing nematodes then consume the bacteria and liquefied host tissues (Kondo and Ishibashi, 1988) [112]. The nematodes-bacteria complex kills the host within 24 to 72 hr (Forst and Clarke, 2002) [71] Concurrence of the biology and ecology of nematodes and the target pest are basic for a successful application (Hazir *et al*., 2003). Native EPNs might be better adapted to the abiotic conditions of a certain locality, and thus extend their persistence, which is an important characteristic for their wider use. Different abiotic factors (soil type, humidity, temperature and pH) influence the establishment and persistence of the nematodes in soil (Kung *et al*., 1990; Grewal *et al*., 1994) [116, 82]. But biotic factors (*i.e.* alternative host availability) also have an effect on the different persistence of nematode species and strains (Strong, 2002) [201].

Control Potentialities of Entomopathogenic Nematodes

Entomopathogenic nematodes have a high control potential when applied to control weevils (Curculionidae) in nurseries (van Tol & Raupp, 2005) [219], tuber crops (Belair *et al*., 2003) [24] and forestry (Torr *et al*., 2007) [213] (Table.1). In general, beetles are very well-armoured insects and thus are reasonably protected against enemies; most, however, have parasites. Research has demonstrated that EPNs at high concentrations, together with favourable abiotic factors (i.e., high humidity, optimal temperature) can be effective biological control agents of chrysomelids (Journey and Ostlie 2000; Trdan *et al*. 2008, 2009) [103, 214]. The application of EPNs in biological control was traditionally used to control soil pests until a few years ago (Ishibashi and Choi 1991) [90]. Research from the last two decades also indicates their potential against foliar pests, but only under special conditions (Arthurs *et al*. 2004) [13]. In the field, various strains of these plum curculio larvae have reduced populations by as much as 70-97%, depending on the nematode strain, insect stage, treatment timing and field conditions. Effective control of larval populations has been achieved if the correct nematode species and strain was selected and effectively introduced into the system. The majority of current research has been directed toward the inundative release using commercially reared nematode strains.

Many species and strains of nematodes have been evaluated for control of Japanese beetle, with varying degrees of success. Entomogenous nematodes vary in their activity against beetle grubs partly because of differences in their host-finding behavior. *Steinernema carpocapsae* uses an ambush strategy to attach to and parasitize moving hosts- so it is usually ineffective against a sedentary, subterranean pest like Japanese beetle. In contrast, both *S. glaseri* and *Heterorhabditis bacteriophora* use a cruising strategy to locate hosts and tend to be more effective against sedentary pests. In one field study in New Jersey, two strains of *H. bacteriophora* and two strains of *S. glaseri* reduced grub populations to a level comparable with that achieved with the standard chemical insecticide (77%). In another field study two strains of *S. glaseri* reduced Japanese beetle grubs by 65%, while a third strain of *S. glaseri*, *S. anomali*, and a *Steinernema* sp. only reduced populations by 44%. Choosing an appropriate strain or species is an important factor in obtaining control of Japanese beetle. Nematodes need both high humidity and a layer of water to move through the soil. *H. bacteriophora* seemed to tolerate both extremes of moisture better than *S. glaseri*. The nematode that was effective for the longest period was *H. bacteriophora* that had been stored at the coolest temperature and was tested in high moisture-content soils.

Table 1: Parasitism of entomopathogenic nematodes in coleopteran insects

Nematode	Insect	Efficacy	Reference
Steinernema carpocapsae 'NY 001' *S. feltiae* 'NY 04' *Heterorhabditis bacteriophora* Oswego	plum curculio *Conotrachelus nenuphar*	Up to 75% mortality	Agnello *et al*., 2014 [1]
S.riobrave *H. bacteriophora*	plum curculio *Conotrachelus nenuphar*	81-88%	Pereault *et al*., 2009 [148]
H. indica SL0708 *S.* sp. JCL024	guava weevil, *Conotrachelus psidii*	37 and 71%	Delgado & Saenz-Aponte, 2016 [49]
H.bacteriophora HP88, *H. baujardi* LPP7,LPP1, *H. indica* Hom1, *S.carpocapsae* All and Mexican, *S. feltiae* SN, *S. glaseri* NC, *S. riobrave* 355	guava weevil, *Conotrachelus psidii*	33.5- 84.5%	Dolinski *et al*., 2006 [50]
S. feltiae SN *S. rarum* 17 C&E *S. riobrave* 355 *H. indica* HOM1 *H. bacteriophora* Oswego *S. kraussei*, *S. carpocapsae* Sal	plum curculio *Conotrachelus nenuphar*		Shapiro-Ilan *et al*., 2011 [186]
S.riobrave *S. feltiae*	plum curculio, *Conotrachelus nenuphar*	77.5-95%	Shapiro-Ilan *et al*., 2013 [185]
Neoaplectana carpocapsae	plum curculio *Conotrachelus nenuphar*		Tedders *et al*., 1982 [204]
S. riobrave	last instar plum curculio larvae	70-97%	Shapiro-Ilan *et al*. 2002, Alston

S. feltiae *S. carpocapsae H.bacteriophora*	*Conotrachelus nenuphar*		*et al*. 2005, Kim and Alston 2008 [181, 7, 109]
S.carpocapsae, *S.feltiae*	*Beet weevil, Conorhynchus mendicus*	68.5-89.5% larvae mortality	Akalach & Wright, 1995 [4]
S. feltiae D114, *Steinernema* sp. D122 *H.bacteriophora* DG46	hazelnut weevil, *Curculio nucum*	32% to 88%	Batalla-Carrera *et al*., 2013 [19]
S. carpocapsae B14 *S. feltiae* D114	hazelnut weevil, *Curculio nucum*	5-20% larval mortality	Batalla-Carrera *et al*., 2014 [20]
S. feltiae *H. bacteriophora*	hazelnut weevil, *Curculio nucum*	43.3% to 75.5%	Kuske *et al*., 2005 [119]
S. feltiae and *H. bacteriophora*	hazelnut weevil, *Curculio nucum*	41% to 75% mortality	Peters *et al*., 2009 [149]
S.sp.	rice water weevil *Lissorhoptrus oryzophilus*	80%	Carbonell, 1983 [49]
S.feltiae	rice water weevil *Lissorhoptrus oryzophilus*		Kisimoto *et al*., 1987 [110]
S. feltiae	rice water weevil *Lissorhoptrus oryzophilus*		Nagata, 1987a [142]
S. carpocapsae *H*.sp.	rice water weevil *Lissorhoptrus oryzophilus*		Grigarick & Oraze, 1990 [84]
S.feltiae,B30, Entonem, *S. carpocapsae* *H. marelatus*	adults of *Sitophilus oryzae* adults of *Oulema melanopus* Colorado potato beetle (*Leptinotarsa decemlineata*	31-100% mortality	Laznik *et al*., 2010a; 2010b;2010c; Stewart *et al*. 1998; Trdan *et al*., 2009; Cantelo, & Nickle, 1992; Armer *et al*., 2004 [121, 122, 123, 198, 215, 39, 12]
Steinernema sp.	sweet potato weevil *Cylas formicarius*	70% mortality	Santoso *et al*., 2009 [164]
H. bacteriophora, *H.indica*, *S.abbasi*, *S.carpocapsae*, *S.glaseri*	Grey weevil, *Myllocerus subfasciatus*	80% mortality	Nagesh *et al*. 2016 [143]
H.bacteriophora	western corn rootworm, *Diabrotica virgifera virgifera*		Hiltpold *et al*., 2009; 2012 [89, 88]
S.carpocapsae All	western corn rootworm, *Diabrotica virgifera virgifera*		Wright *et al*., 1993 [224]
Neoaplectana carpocapsae *H.bacteriophora* *H.megidis*, *S.feltiae*, *S.carpocapsae* *S.diaprepesi*, *S.riobrave*	*Diabrotica virgifera virgifera*		Poinar *et al*., 1982;1983; [155, 154] Pilz *et al*., 2008; 2009; 2011; [153, 152, 151] Geisert *et al*., 2018 [73]
Neoaplectana carpocapsae	striped cucumber beetle *Acalymma vittatum*		Reed *et al*., 1986 [158]
S.carpocapsae	western corn rootworm, *Diabrotica virgifera virgifera*		Journey & Ostlie, 2000 [103]
S.carpocapsae Mexican *S. feltiae* *S. glaseri.*	western corn rootworm, *Diabrotica virgifera virgifera*		Jackson *et al*.,1985; [96] Jackson & Brooks, 1989;1995; [95, 94] Jackson, 1995;1996;1997 [94, 93, 92]
H.bacteriophora *H. megidis* *S.feltiae*	western corn rootworm *Diabrotica virgifera virgifera*		Kurtz *et al*., 2007; 2009 [117, 118]
H. sp. RSC01 *S. glaseri* *H*.sp. JPM04 *H. amazonensis* RSC05	*Diabrotica speciosa*	82-94%	Santos *et al*., 2011 [163]
H. megidis	western corn rootworm *Diabrotica virgifera virgifera*		Rasmann *et al*., 2005 [157]
H.bacteriophora	western corn rootworm *Diabrotica virgifera virgifera*	25-79%	Toepfer *et al*. 2005; 2008; 2010; 2010a; 2010b; 2012 [207, 210, 206, 208, 211]
S.feltiae, *S bibionis* *H.bacteriophora*	*Sitona hispidulus*		Wiech & Jaworska, 1990 [222]
H.bacteriophora Oswego	clover root curculio, *Sitona hispidulus*		Loya & Hower, 2003 [129]
H.bacteriophora *H. indica* *S. feltiae*	chestnut weevil	43.3-75.4%.	Kuske *et al*., 2005 [119]
S. feltiae B30, *S. carpocapsae* C101, *H. bacteriophora* D54 Entonem	adult cereal leaf beetles *Oulema melanopus*	100%	Laznik *et al*., 2010a [121]

S. feltiae B30, Entonem	Colorado potato beetle *Leptinotarsa decemlineata*		Laznik *et al*., 2010c [122]
H.bacteriophora(Brecon) *H.indicus*(FL2122) *H.marelatus*(OH10), *H*.sp.(OH23), *H*.sp.(OH95) *S.oregonense*(OS21) *S.riobrave*(TX)	fourth instar Colorado potato beetle *Leptinotarsa decemlineata*		Berry *et al*. 1997 [28]
DD136	Colorado potato beetle, *Leptinotarsa decemlineata*		Welch & Briand, 1961 [221]
S. carpocapsae *S. bibionis* *S. feltiae* *S. glaseri* *S*.sp.85011, 8602, 8508 and 8503, *H. heliothidis*10 strains	bamboo weevils *Cyrtotrechalus longimanus*		Liu *et al*., 1989 [125]
S.feltiae B30, B49 and 3162	Adult rice weevil *Sitophilus oryzae*	42-72% mortality	Laznik *et al*., 2010b [123]
S.carpocapsae (All,Mexican)	Corn rootworm, 2nd and 3rd instar of *Diabrotica* sp.		Ellsbury *et al*., 1996 [65]
Heterorhabditis sp.	potato weevil *Premnotrypes suturicallus*		Alcazar *et al*. 2007 [5]
S.carpocapsae *S. feltiae* *H.indica* *H.bacteriophora*	larvae and pupae of vine weevil *Otiorhynchus sulcatus*		Mahar *et al*., 2005 [130]
H.megidis	black vine weevil *Otiorhynchus sulcatus*		Lola-Luz *et al*., 2005; [127] Lola-Luz & Downes, 2007 [126]
H.bacteriophora *S. feltiae*	Black vine weevil, *Otiorhynchus sulcatus*	35-40% mortality	Ansari *et al*., 2008 [10]
S. carpocapsae Exhibit S. kraussei L137	Black vine weevil *Otiorhynchus sulcatus*		Willmott *et al*., 2002 [223]
Steinernema spp., *Heterorhabditis* spp.	white fringed weevils *Naupactus durius* , *Pantomorus auripes*, *Graphognatus leucoloma*		Ahmad, 1974a;1974b; [2, 3] Stock, 1993 [203]
Neoaplectana dutkyi DD-136	white-fringed beetle, *Graphognathus peregrinus*	38%	Harlan *et al*., 1971 [86]
S.carpocapsae *S.glaseri* *S. feltiae* *H.bacteriophora*	Japanese beetle, *Popillia japonica*, Oriental beetle, *Anomala orientalis*, black turfgrass ataenius, *Ataenius spretulus*	81-94% larvae mortality	Alm *et al*., 1992 [6]
S.glaseri	*Japanese beetle* *Popillia japonica Oriental beetles* *Exomala orientalis*,		Yeh & Alm, 1995 [227]
H.bacteriophora *S*. sp.	white grub, *Polyphylla olivieri*		Parvizi, 2001
H.bacteriophora *H.bacteriophora*	Grubs, *Phyllopertha horticola* *Aphodis contaminatus*	40-83%	Sulistyanto & Ehlers, 1996 [147]
H. bacteriophora *S. glaseri* *S. kushidai*	Japanese beetle, *Popillia japonica* oriental beetle, *Exomala orientalis* masked chafers *Cyclocephala borealis* *C. pasadenae*, *C. hirta*		Koppenhofer *et al*., 2000a; 2000b [113, 115]
S.carpocapsae *N. glaseri* *H.heliothidis*	Japanese beetle, *Popillia japonica*	53-73%	Shetlar *et al*., 1988 [189]
S. scarabaei AMK001 *S. glaseri* NC1 *H. zealandica* X1 strain *H. bacteriophora* GPS11	third-instars of *Popillia japonica*, *Anomala orientalis*, *Cyclocephala borealis*, *Rhizotrogus majalis*	1.5-14%	Koppenhofer *et al*., 2007 [114]
S. feltiae Otio,A54 *S.ceratophorum* D43 *S.carpocapsae* B	*Luperomorpha suturalis*	13.9-92.4%	Yang *et al*., 2003 [226]
H.bacteriophora HbCLO51 *H. megidis* HmVBM30 *H. indica*, *S.scarabaei*, *S. feltiae*, *S. arenarium*, *S. carpocapsae* ScBE *S. glaseri* SgBE *S. glaseri* SgNC	Second, third-instar larvae and pupae of *Hoplia philanthus*	57–76% larval mortality	Ansari *et al*., 2004; 2006; 2008; [9, 10, 8]

H.bacteriophora	*Holotrichia consanguinea*		Yadav *et al*., 2004 [225]
S. feltiae, *S. carpocapsae*, *H.bacteriophora*	Adults of *Holotrichapion pullum*	24.15- 82.15% mortality	Atay & Kepenkci, 2016 [15]
H.bacteriophora	red palm weevil, *Rhynchophorus ferrugineus*		Atakan *et al*. 2009 [14]
S.carpocapsae	Larvae of *Rhynchophorus ferrugineus*		Manachini *et al*., 2013 [131]
*H.bacteriophora*ZET35 *S.feltiae*ZET 31 *S.websteri*AS-1	Pre-pupae and adults of alder leaf beetle, *Agelastica alni*	79.17 and 71.11% mortality	Bayramoglu *et al*., 2018 [21]
H.bacteriophora HP88 *S.glaseri* NJ	third instar larvae of *Temnorhynchus baal*	60-90% larval mortality	Atwa & Hassan, 2014 [18]
H. indica	*Temnorhynchus baal*		Shehata *et al*., 2019 [188]
Neoaplectana carpocapsae, *Heterorhabditis* sp.	*Diaprepes abbreviatus*		Beavers *et al*., 1983 [22]
Heterorhabditis sp. *Neoaplectana carpocapsae*,	*Diaprepes abbreviatus*		Roman & Beavers, 1983; Roman & Figueroa, 1985 [159, 160]
Neoaplectana carpocapsae, *N.glaseri*	*Diaprepes abbreviatus*	35-65%	Schroeder, 1987; 1990 [168, 167]
H. bacteriophora Baine, NJl, Hb, Hbl, HP88, Lewiston *H. indica* original and Homl *H. marelatus* IN and Point Reyes *H. megidis* UK21l *H. zealandica* NZH3 *S. riobrave* 355 *S. carpocapsae* All *S. feltiae* SN and UK76 *S. glaseri* NJ43	root weevil, *Diaprepes abbreviatus*		Shapiro *et al*., 1999; [177] Shapiro *et al*., 2000; [174] Shapiro & McCoy, 2000; 2000a; 2000b; [175, 176, 178] Shapiro-Ilan, 2001; [179] Shapiro-Ilan *et al*., 2002; [181]
H. bacteriophora *S. carpocapsae*	lady beetles *Coleomegilla maculata* *Olla vnigrum*, *Harmonia axyridis Coccinella septempunctata*	lower host suitability	Shapiro-Ilan & Cottrell, 2005 [180]
S. glaseri *H.bacteriophora*	Japanese beetle larvae *Popillia japonica*	11-40%	Wang *et al*., 1995 [220]
H.bacteriophora HP88, New Jersey,NJ-2 *S.glaseri* NC,New Jersey, NJ-43	*Popillia japonica*	51-71.6%	Selvan *et al*., 1993 [169]
S. scarabaei	scarab beetles *Anomala (= Exomala) orientalis* , *Popillia japonica*		Stock & Koppenhofer, 2003 [203]
S.glaserl *S.carpocapsae*	chafer *Holotrichia Consanguinea*		Shanthi & Sivakumar, 1991 [173]
S.glaseri NC,New Jersey,NJ-43,51-12 *S.anomali* Ryazan *S.*sp.RGV	*Popillia japonica*	44-66%	Selvan *et al*., 1994 [170]
S. pakistanense Ham 10 *S. asiaticum* 211 *S. abbasi* 507 *S. siamkayai* 157 *S. feltiae* A05 *H.bacteriophora* 1743 *H. indica*	pulse beetle, *Callosobruchus chinensis*		Shahina & Salma, 2010 [171]
H.heliothidis *H.* sp. (HP88 *Neoaplectana carpocapsae* All	black vine weevil *Otiorhyncus sulcatus*	70%	Simons, 1981; [194] Shanks & Agudelo-Silva, 1990 [172]
S. carpocapsae *H.megidis*	black vine weevil, *Otiorhynchus sulcatus*	26-65%	Kakouli-Duarte *et al*., 2008 [104]
H.heliothidis NC19 *Heterorhabditis* sp. NC447 *S. feltiae* A32-6	black vine weevil *Otiorhyncus sulcatus* strawberry root weevil *O. ovatus* L.		Rutherford *et al*. 1987 [161]
H. heliothidis T327 *Neoaplectana bibionis*	black vine weevil, *Otiorhynchus sulcatus*	87% parasitisation	Bedding & Miller, 1981 [23]
S. kraussei L017 and L137 *S. feltiae* Nemasys®) *H. megidis* Nemasys®	larvae and pupae of the vine weevil *Otiorhynchus sulcatus*		Long *et al*., 2000 [128]
H.bacteriophora Oswego *H.bacteriophora* NC *S.carpocapsae* NY001 *S.*sp.NY008-2E	alfalfa snout beetle *Otiorhynchus ligustici*		Ferguson *et al*., 1995 [66]
H.bacteriophora Oswego *S.carpocapsae* NY001	alfalfa snout beetle *Otiorhynchus ligustici*		Shields *et al*., 2009 [190]

H.heliothidis	Strawberry weevil (larvae and pupae), *Otiorhynchus sulcatus*, *Phlyctinus callosus*	59 and 25% mortality	Curran & Patel, 1988 [46]
H.megidis UK211	*Otiorhynchus sulcatus*	41% mortality	Fitters *et al*., 2001 [69]
S.carpocapsae All *S.feltiae* *H.bacteriophora* CI,HP88	Larvae and pupae of black vine weevil *Otiorhynchus sulcatus*		Hanula, 1993 [85]
H.marelatus, H.bacteriophora, S. riobrave	Black vine weevil, *Otiorhynchus sulcatus*	100% larvae mortality	Bruck *et al*., 2005 [33]
H.marelatus, H.bacteriophora	Larvae and pupae of root weevil, *Otiorhynchus ovatus, O.sulcatus*	75.3 and 77.4% mortality	Berry *et al*. 1997 [27]
H.bacteriophora NC *H.bacteriophora* Oswego	alfalfa snout beetle *Otiorhynchus ligustici*		Shields *et al*., 1999 [191]
S.feltiae (= *bibionis*) FN *H. bacteriophora* NC1	black vine weevil, *Otiorhynchus sulcatus*	50%.	Burlando *et al*., 1993 [36]
H. indica, S. carpocapsae S. thermophillum	alfalfa weevil, *Hypera postica*		Schroeder *et al*., 1994 [166]
Steinernema sp	sweet potato weevil, *Cylas formicarius*		Santoso *et al*., 2009 [164]
S.carpocapsae	*Cosmopolites sordidus*		Schmitt *et al*., 1992 [165]
H. sp. (NL-HL81), *H. bacteriophora* (HP 88) *S.carpocapsae* ("All")	sugarbeet weevil larvae, *Temnorhinus mendicus* (*Conorhynchus mendicus*)		Curto *et al*., 1999 [47]
H. bacteriophora H. megidis	hazelnut borer, *Curculio nucum*	72%	Blum *et al*. 2009 [149]
H.bacteriophora	pecan weevil, *Curculio caryae*		Nyczepir *et al*., 1992 [145]
S.carpocapsae S. feltiae H. bacteriophora H. indica	hazelnut borer, *Curculio nucum*	23-76%	Peters, 1996; Peters *et al*., 2009 [150, 149]
S.carpocapsae, H. indica	pecan weevil, *Curculio caryae*		Shapiro-Ilan *et al*., 2004; 2005 [180, 182]
S. carpocapsae All, *S. feltiae* SN, *H.bacteriophora* HP88 , Georgia	pecan weevil, *Curculio caryae*		Smith *et al*., 1993 [196]
S. carpocapsae H. bacteriophora H. indica H. marelatus	Asian longhorn beetle, *Anoplophora glabripennis*		Solter *et al*., 2001 [197]
S.feltiae (DD 136, Listronotus)	carrot weevil, *Listronotus oregonensis*	decreased the oviposition rate	Boivin & Belair, 1989 [30]
S.carpocapsae, S. riobrave, S. feltiae, H.megidis, H. bacteriophora	carrot weevil *Listronotus oregonensis*		Miklasiewicz *et al*., 2002 [139]
S. carpocapsae H. bacteriophora S.feltiae S.kraussei	annual bluegrass weevil, *Listronotus maculicollis*,	50% mortality	McGraw & Koppenhofer, 2008 [138]
S.carpocapsae	*Listronotus oregonensis*	reduced the oviposition of adults, reduced damage by up to 59%.	Belair & Boivin, 1995 [25]
S. feltiae, S. bibionis, H.heliothidis	Larvae, pupae, and adults of the carrot weevil , *Listronotus oregonensis*		Belair&Boivin,1985;1995 [30, 25]
S feltiae, S. carpocapsae H.bacteriophora	flatheaded root borer, *Capnodis tenebrionis*	50-100% mortality	Morton & Garcia-del-Pino, 2009 [140]
Heterorhabditis sp.(NH-HL81)	adult *Temnorrhinus mendicus (Conorhynchus mendicus)*		Boselli *et al*., 1991 [31]
H sp. (NL-HL81), *H. bacteriophora* (HP 88) *S. carpocapsae* (All)	larvae of *Temnorhinus mendicus*		Boselli *et al*. 1997 [32]
Neoaplectana carpocapsae	large pineweevil, *Hylobius abietis*		Pye & Burman, 1977 [156]
Neoaplectana carpocapsae, S.carpocapsae, H.downesi	large pine weevil, *Hylobius abietis*		Burman *et al*., 1979; [37] Skrzecz *et al*., 2011 [195]
S. riobrave TX- 355	boll weevil , *Anthonomus grandis*	15 to 100%	Cabanillas, 2003 [38]

S. glaseri NC , *H. indicus* HOM-1 , *H. bacteriophora* HbL , *H. bacteriophora* IN *S. riobrave* TX *H. bacteriophora* HP88			
S.carpocapsae *S.glaseri* *H.bacteriophora*	white grubs, *Ectinohoplia rufipes* *Exomala orientalis*	79.4-82.8%	Choo *et al*., 2002 [41]
S.carpocapsae *H.heliothidis*	white grubs	12%	Forschler & Gardner, 1991 [70]
H.riobravus *S.carpocapsae*	*Alphitobius diaperinus*		Costa *et al*., 2007 [42]
Heterorhabditis sp	banded cucumber beetle, *Diabrotica balteata*	95%	Creighton & Fassuliotis, 1985 [45]
S. rarum CUL *H.bacteriophora* SMC	*Diloboderus abderus*	45-95% larval mortality	Del Valle *et al*., 2017 [48]
S. feltiae	chestnut curculio, *Curculiodentipes Roelofs*		Nagata, 1987 [141]
H.bacteriophora	Japanese beetle, *Popillia japonica* Northern masked chafer, *Cyclocephala borealis*	80%	Downing, 1994 [54]
H. zealandica X1 , *H. bacteriophora* GPS11 *H. bacteriophora* KMD10 and NC1. *H.indica* *H. marelatus*	*Popillia japonica* *Cyclocephala borealis*	20-50% mortality	Grewal *et al*., 2002 [80]
H.bacteriophora *S. glaseri*	*Cyclocephala hirta*		Thurston *et al*. 1994 [205]
S.carpocapsae, *H*.sp.	Citrus weevil, *Diaprepes abbreviates*, *Pachnaeus litus*, *P.opalus*, *Artipus floridanus*		Downing *et al*.,1991; [55]
S. carpocapsae , *S. riobravis*	sugarcane root stalk borer weevil, *Diaprepes abbreviatus* citrus root weevil, *Pachnaeus litus*	64% and 89% reduction	Bullock & Miller,1994; Bullock *et al*., 1999 [34, 35]
S. feltiae *S. glaseri* *S.bibionis*	sugarcane rootstalk borer, *Diaprepes abbreviatus*	85% mortality	Figueroa & Roman, 1990 [67]
S. feltiae *S.riobrave* 3-8b,TP,7-12,355 *H.indica* HOM1 *S.rarum*	*Diaprepes abbreviatus*		Jenkins *et al*. 2007 [102]
H.bacteriophora, *S. carpocapsae*, *S. riobravis*	larvae of *Diaprepes abbreviatus*	50-90%	Duncan & McCoy, 1996; [56] Duncan *et al*., 1996; 1999; 2001; [58, 59, 57]
S. riobrave, Biovector 355 *H.bacteriophora*, *H. indica* Grubstake100	*Diaprepes abbreviatus*		McCoy *et al*., 2000; 2002 [136, 137]
H. megidis *S. feltiae*	sweet potato weevil, *Cylas formicarius*	70-90%	Ekanayake *et al*., 2001 [61]
S. carpocapsae Agriotos,All,Breton, Italian,Mexican *S. feltiae* N27 *S.intermedia* *H.bacteriophora* HP88,North Carolina *H*.sp. FL2122	sweet potato weevil, *Cylas formicarius*	25-60%	Mannion & Jansson, 1992a; 1992b; 1993 [132-134]
S. carpocapsae All,S17,S20 *S. feltiae* N27 *H.bacteriophora* HP88 *H*.sp.Bacardis	sweet potato weevil *Cylas formicarius*		Jansson *et al*., 1990; 1991; 1993 [97-99]
S.karii *H.indica*	sweet potato weevil *Cylas puncticollis*		Nderitu *et al*., 2009 [144]
S. feltiae, *S. bibionis* *H.bacteriophora*	clover root weevil, *Sitona hispidulus*		Jaworska & Wiech , 1988 [101]
Steinernema yirgalemense, *S. jeffreyense*, *Heterorhabditis indica*	longhorned beetle *Cacosceles newmannii*		Javal *et al*., 2019 [100]
S. riobravis	*Acalymma vittatum*	50% larval mortality	Ellers-Kirk *et al*., 2000 [63]
S. riobrave *H. indica*	*Aethina tumida*	88-100%	Ellis *et al*., 2010 [64]

Neoaplectana carpocapsae *S. glaseri* *S.bibionis*	root borer weevil, *Cosmopolites sordidus*		Figueroa, 1990 [67]
H.sp.	Sap beetles of date palm,nitidulid beetle	50-70%	Glazer *et al*., 2007 [77]
Steinernema sp3 JCL027, *S. feltiae* SCT125, *S. websteri* JCL006, *S. colombiense* SNI0198, *H.bacteriophora* HNI0100, *H. bacteriophora* HASA702, *H. indica* SL0708	3rd instar larvae of oil palm "chiza" *Strategus aloeus*	19.3-22% mortality	Gomez & Saenz-Aponte, 2015 [78]
S. riobravis	pink bollworm *Pectinophora gossypiella*	100%	Gouge *et al*., 1996 [79]
S.carpocapsae, *S. feltiae* *H. bacteriophora*	great spruce bark beetle *Dendroctonus micans* lesser grain borer adults *Rhyzopertha dominica*	38.8-94% mortality	Kepenekci & Atay, 2014; Kepenekci *et al*., 2014 [107, 108]
S. feltiae 09-31), *S. carpocapsae* (Black sea isolate) , *H. bacteriophora* 09-43	lesser grain borer adults *Rhyzopertha dominica*	37.95 -54.06%	Tulek *et al*., 2015 [218]
S. feltiae *S. carpocapsae*	*Tribolium confusum Rhyzopertha dominica*	23.3- 41.7%	Athanassiou *et al*., 2008; 2010 [16, 17]
H. indica HOM1 *H. bacteriophora* Baine,Oswego *H.georgiana* Kesha *S. riobrave* 355 *S. carpocapsae* All *S. feltiae* SN	Weevil of ornamental plants, *Stethobaris nemesis*		Shapiro-Ilan *et al*., 2012 [187]
S.feltiae TUR-S3 *S. weiseri* BEY *H. bacteriophora* TUR-H2	sugar beet weevil *Bothynoderes punctiventris*		Susurluk, 2008 [203]
H.megidis *S. feltiae*	tree leaf beetles *Altica quercetorum Agelastica alni*		Tomalak, 2004 [212]
S. feltiae *S. carpocapsae* *H. bacteriophora* *H.megidis*	Stored grain pest *Sitophilus granarius Oryzaephilus surinamensis*		Trdan *et al*., 2006 [216]
S. carpocapsae All *S. carpocapsae* NC513	*Cosmopolites sordidus*		Treverrow *et al*., 1991 [217]
S.feltiae *S. carpocapsae H.bacteriophora* *H. megidis*	adult flea beetles, *Phyllotreta* spp.	44-74% mortality	Trdan *et al*., 2008 [214]

Conclusion
Nematodes are part of an evolutionary process adapted to survival of the species. Incorporation of biological control agents such as entomopathogenic nematodes with proper strain into orchard pest management systems has been projected as a way to reduce the potential for resistance development (Lacey *et al*., 2015) [120].

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