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RESEARCH ARTICLE

WHITE GRUB MANAGEMENT BY ENTOMOPATHOGENIC NEMATODES

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ABSTRACT

White grub cause extensive damage to many agricultural and horticultural crops as well as turf grass. The pests are difficult to control due to the cryptic habit of the larvae in the soil. Cultural, mechanical and chemical methods of control are recommended for the management of these pests. The application and/or management of pathogenic microorganisms have been advocated as an ecofriendly control strategy for insect pests. One of the promising biological control agents is the entomopathogenic nematodes for the management of white grub populations. Entomopathogenic nematodes offer an environmentally safe and IPM compatible alternative to chemical insecticides for the control of white grubs.

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INTRODUCTION

The scarab beetles included in Melolonthidae and Scarabaeidae family of Coleoptera order (Borror *et al*., 1992). Their larvae live in the soil and are commonly known as white grubs. The family Scarabaeidae has a high diversity of species, varying widely in size, color and biological traits. Some of these have become important pests, causing extensive damage to the roots of grasses, legumes, fruit plants, shrubs and trees in many parts of the world. The damage caused by this pest is observed in patches but during epidemics the entire crop may be exhausted. More than 1000 species of white grubs are known from India of which over 40 species attack a wide range of crop plants. *Holotrichia longipennis* Blanch, *H.consanguinea* Blanch, *H.reynaudi* Blanch, *H.serrata* Fab., *H.seticollis* Moser, *Brahmina coriacea* (Hope), *Anomala dimidiata* (Hope), *Leucopholis lepidophora* Blanch, *L.coneophora* Brum., *Melolontha* spp., and *Lepidiota* spp. are the key pest species that attack different plants in different regions of the country. In the United States, larvae of the introduced Japanese beetle, *Popillia japonica* Newman, are a major pest of turf grass and ornamentals, and native masked chafers, *Cyclocephala* spp., larvae are major pests of turf grass and ornamentals (Potter, 1998; Vittum *et al*., 1999). The European chafer, *Rhizotrogus majalis* (Razoumowsky), the Asiatic garden beetle, *Maladera castanea* (Arrow), and the oriental beetle, *Exomala* (=*Anomala*) *orientalis* Waterhouse have become similar in importance as turf grass and ornamental pests as the Japanese beetle (Alm *et al*.,1999). The feeding activity of white grubs and chafers in crops not only reduces yields by themselves and but also facilitates secondary microbial infections through the damaged plant cuticle (Smith *et al*., 1995; Miller *et al*., 1999).All these white grub species have an annual life cycle with adults emerging in summer to lay eggs in the soil among the roots of the host plants. By late summer most larvae have developed into the third instar. After overwintering the larvae resume feeding in spring until pupation in late spring. The extensive feeding activity of the larger larvae can damage large areas of grass especially under warm dry conditions.

Management: The pests are difficult to control due to the cryptic position of the larvae in the soil and the usually nocturnal activity of the adults. Currently, cultural, mechanical and chemical methods of control are recommended for the suppression of these pests. Chemical control however, has led to problems of residues, pest resurgence, insecticide resistance and failure of economic control. Different cultural practices, such as ploughing, harrowing, hoeing, flooding and fallowing of fields, trap cropping and crop rotation, have been suggested by various workers. Mechanical method such as collection and destruction of adults during their peak periods of manifestation is effective. The application and/or management of pathogenic microorganisms have been promoted as an alternative control strategy for insect pests.

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Table 1. Efficacy of entomopathogenic nematodes against white grub species

Entomopathogenic nematodes	Insect spp.	crop	achievement	References
Neoaplectana glaseri	*Popillia japonica*		parasite	Steiner,1929
N. glaseri	*Popillia japonica*		parasitic	Glaser ,1932
N. hoptha	*Popillia japonica*		parasitic	Turco ,1970
N.glaseri	*Strigoderma arboricola*		parasitic	Poinar,1978
N.glaseri	third instar grass grub of *Costelytra zealandica*		66% control	Kain *et al*.,1982
Heterorhabditis bacteriophora				
DD-136	*Anomala* sp.		effective	Rajeswari *et al*., 1984
H. megidis	Popillia japonica		parasitic	Poinar *et al*., 1987
Heterorhabditis sp.V16	grass grub		Able to infect	Jackson & Wouts, 1987
S.feltiae	*Phyllophaga anxia*		60-80% reduction	Kard *et al*.,1988
H.heliothidis	*P.fusca* *Polyphylla comes*			
N. carpocapsae	Japanese beetle	Turfgrass	53%	Shetlar *et al*., 1988
N.glaseri				
H.heliothidis			73%	
S.feltiae	3rd instar grub of *Rhizotrogus majalis*			Villani & Wright, 1988
H. heliothidis				
H.heliothidis	*Popillia japonica, Rhizotrogus majalis*	Turfgrass	94% control	
			>60% control	
S. feltiae	3rd instar grub of *Popillia japonica, Rhizotrogus majalis*	*Taxus cuspidata*	29% control	Wright *et al*., 1988
S. glaseri			84%	
H. heliothidis	*Popillia japonica*		>90%	
H.sp. Holland				
Steinernema sp.	scarabaeid larvae			Hatsukade *et al*., 1988
H.sp.HP88	Maladera matrida		86% control	Glazer & Gol'berg, 1989
H.sp. HL81			30-47% control	
S. feltiae 'All'				
S.bibionis CR				
S. glaseri	Japanese beetle		90 % reduction	Wright *et al*., 1989
S.carpocapsae	White grub	turf	12% control	Forschleri & Gardner, 1991
H.heliothidis				
S.carpocapsae	*3rd instar grub of* Phyllophaga hirticula		LC_{50}:210	
S. glaseri			LC_{50}:86	
H.heliothidis			LC_{50}:12	
S. glaseri	*Popillia japonica*	turf and pasture	Better reduction than Isofenfos	Georgis & Hague ,1991
S. glaseri	*Holotrachia consanguinea*		virulent	Shanthi & Sivakumar, 1991
S.carpocapsae				
S.carpocapsae	*Ataenius spretulus*		94% mortality	Alm *et al.,* 1992
S.glaseri	*Popillia japonica*		81% mortality	
Heterorhabditis spp.	3rd instar larvae of *Lepidioca crinita, L.negawria , L.picticollis,* pre-pupae and pupae of *Antitrogus consanguineus*	sugar cane	26-100% infection	Akhurst *et al*., 1992
H.bacteriophora NC	Popillia japonica		96 % control	Klein & Georgis, 1992
S.carpocapsae			90% control	
H.bacteriophora HP88			100% control	
S.carpocapsae All	*Popillia japonica*		17.8-99.4% mortality	Yeh & Alm, 1992
S.carpocapsae Mexican				
S.feltiae Biosys 27				
S.glaseri Biosys 2				
H.bacteriophora HP88				
H.bacteriophora C1				
H.bacteriophora	*Amphimallon solstitialis*		parasitic	Glare *et al.,* 1993
H.bacteriophora	Maladera matrida	peanuts	93% population reduced	Glazer & Gol'berg, 1993
H. sp. Taishan No.1	*Holotrichia parallela , H.oblita*	peanut	pathogenic	Li *et al.,*1993
S. kushidai	3rd instar grubs of cupreous chafer	Sweet potato	Reduced number	Ogura, 1993
H. bacteriophora HP88	*Popillia japonica*		51% mortality	Selvan *et al*., 1993
H. bacteriophora NJ-2			71.6%	
S.glaseri NC			50.4%	
S.glaseri NJ-43			70.1%	
S. carpocapsae Breton	immature stages of *Popillia japonica*		56% mortality	Simoes *et al.,* 1993
S. glaseri			100% mortality	
H.bacteriophora				
H.bacteriophora Oswego	*Popillia japonica*		Grubs infected	Schroeder *et al*., 1993

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S.glaseri NC	*Popillia japonica*		44% reduction	Selvan *et al*., 1994
S.glaseri NJ-43			66	
S.glaseri SI-12			65	
S.anomali Ryazan				
S.sp.RGV				
H.bacteriophora C1	Popillia japonica, Cyclocephala borealis	Poa pratensis	80% control	Downing, 1994
S. glaseri	*Popillia japonica, Exomala orientalis*		Reduced larval density	Yeh & Alm, 1995
H.megidis	Phyllopertha horticola, Aphodius contaminatus		70-83% reduction	Sulistyanto & Ehlers,1996
H.bacteriophora			40-62% reduction	
S. glaseri	*Melolontha melolontha*		67%-70% mortality	Vlug ,1996
S. glaseri NJ65	Cyclocephala hirta		76.5% mortality	Converse & Grewal,1998
S. glaseri NJ21			100% mortality	
S. glaseri NJ29				
S. glaseri NJ42				
*H.sp.*Chino hill			45-66.7% mortality	
S.anomali				
H.megidis				
H.bacteriophora				
H.bacteriophora	2nd instar grub of *Cotinis nitida*		34% mortality	Townsend *et al*., 1998
S. glaseri			22%	
S. feltiae			18%	
S. carpocapsae			12%	
H. indicus	*Holotrichia serrata, Leucopholis lepidophora*		Higher mortality	Karunakar *et al*., 2000
S. glaseri				
S. kushidai	*Cyclocephala hirta, Popillia japonica*	turfgrass	better performance in mortality than diazinon	Koppenhofer *et al*., 2000
H. bacteriophora				
H.marelatus	Popillia japonica		50% reduction	Mannion *et al*., 2000
H.sp. São Mateus *H.sp.* Praia Formosa	3rd instar grub of *Popillia japonica*		effective	Lacey *et al*., 2001
H.bacteriophora HP88	Early instars of *Popillia japonica*		65% reduction	Mannion *et al*., 2001
H.marelatus			53% reduction	
S.glaseri	3rd instar *Rhizotrogus majalis*		virulent	Simard *et al*., 2001
S. feltiae				
S. carpocapsae				
H.bacteriophora				
S.carpocapsae (BioSafe)	*Ectinohoplia rufipes, Exomala orientalis*		78.3 to 97% larval reduction	Choo *et al*., 2002
S. glaseri Dongrae				
S. glaseri Hanrim				
H.bacteriophora Hamyang				
H. zealandica X1	*Popillia japonica*		< 50%	Grewal *et al*., 2002
H.bacteriophora GPS11				
H. zealandica X1	C. borealis			
H. bacteriophora KMD10				
H. bacteriophora NC1				
H.indica	*Popillia japonica,* C. borealis		>20%	
H. marelatus				
H. zealandica	P. japonica		Most susceptible host	
H. megidis UK	*Anomala* orientalis			
	Rhizotrogus majalis			
	C. borealis			
H.bacteriophora Jeju	*Adoretus tenuimaculatus*		95% mortality	Lee *et al.,* 2002
H. sp. Gyeongsan				
S. carpocapsae Pocheon				
S. glaseri Dongrea				
S. longicaudum Nonsan				
S. carpocapsae Pocheon	**Exomala orientalis**		50-80% mortality	
S. glaseri Dongrea				
S. glaseri Mungyeong				
S. longicaudum Nonsan				
S. longicaudum Gongju				
H. sp. Gyeongsan			100% mortality	

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H.bacteriophora,CLO-51 *H.bacteriophora*,CLO-52	*Hoplia philanthus,* *Melolontha melolontha*	roadside verge, *Pinus nigra*, lawns and a public garden in Belgium	Natural infestation	Ansari *et al.,* 2003
H. megidis	Hoplia philanthus	perennial ryegrass	80% mortality	Ansari *et al.,* 2003
S. glaseri				
S. feltiae			16% mortality	
S. scarabaei	Rhizotrogus majalis, Popillia japonica		88% mortality 54% mortality	Cappaert & Koppenhöfer, 2003
S. glaseri				
H.bacteriophora				
H.bacteriophora (Nema - green)	*Phyllopertha horticola*		Susceptible host	Ehlers *et al*., 2003
H.bacteriophora	*3rd instar grub of* Maladera castanea		Not effective	Koppenhofer & Fuzy, 2003
S. glaseri				
S. scarabaei			Effective, 71-86% control	
S.scarabaei	*Anomala orientalis, Popillia japonica*	turfgrass	parasite	Stock & Koppenhöfer, 2003
S. feltiae	Third instar grubs of *Maladera insanabilis*		*H.bacteriophora* more virulent than others	Bhatnagar *et al*.,2004
S. species				
Ecomax				
H.bacteriophora				
S. glaseri				
JFC				
H. sp.				
H.indica	white grub	coconut and clove		Gulsar Banu *et al*., 2004
H. zealandica X1	Second and third instar grubs of *Popillia japonica*		73-98% control	Grewal *et al*., 2004
	Cyclocephala borealis		72–96%	
H.bacteriophora GPS11	*Popillia japonica*		34–97%	
	Cyclocephala borealis		47–83%	
H. bacteriophora HP88	*Popillia japonica*		52%	
	Cyclocephala borealis		36%	
S. glaseri NJ *S. glaseri* MB	*Popillia japonica*		20%	
	Popillia japonica		6–58%	
	Cyclocephala borealis		0%	
H.bacteriophora	third instars of 12 white grub species		Popillia japonica highly susceptible	Koppenhofer *et al.,* 2004
S. glaseri				
S. scarabaei				
S.scarabaei	*Exomala orientalis, Popillia japonica, Cyclocephala borealis, Rhizotrogus majalis*		Excellent control	Koppenhofer & Fuzy, 2003; Koppenhofer *et al*.,2004
S. glaseri				
H.bacteriophora				
H. bacteriophora	*Popillia japonica, Anomala orientalis*		Efficacy decrease from third instars to pupae	Koppenhofer & Fuzy, 2004; Koppenhofer *et al*.,2013
S. scarabaei				
H.bacteriophora	3rd inststr grub of *Holotrichia consanguinea*		70-80% mortality	Yadav *et al*., 2004
S. glaseri	Third instar grub of Hoplia philanthus		Natural infestation	*Ansari et al., 2005*
H.indica	Brahmina coriacaea		80.46-100% mortality	Chandel *et al*., 2005
S.glaseri Belgian strain	first, second and third instar grub of *Melolontha melolontha,* *Hoplia philanthus,* *Serica brunnea*		Virulent to all the stages and insects	Ansari *et al*., 2006
S. scarabaei			Virulent to 2nd and 3rd instar of *Melolontha melolontha*	
H.bacteriophora GPS11	*Popillia japonica, Anomala orientalis, Cyclocephala borealis, Rhizotrogus majalis, Maladera castanea*		Virulence differed, but all are susceptible	Koppenhofer *et al*., 2006; Koppenhofer *et al*.,2007
H.bacteriophora TF				
H. zealandica				
S. scarabaei				
H.indica LN2	pupae and adult of *Holotrichia serrata*		100% mortality	Sankaranarayanan *et al*.,2006
H. bacteriophora				
S. glaseri				
S. riobrave				
Oscheius sp.	Peanut grub	peanut	96% control	Liu *et al.,*2007
H. sp. HNI-Cenicafé	L1, L2, L3 young, L3 mature and Prepupae of **Phyllophaga menetriesi,** **Anomala inconstans**		84.7% control	Liliana *et al*., 2007
S. feltiae Villapinzón			L2 more susceptible 76.7% control	

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S.scarabaei	third-instar Anomala orientalis		50–95% control	Polavarapu *et al*., 2007
H.bacteriophora			ineffective	
H.bacteriophora CLO51	against second, and third instar larvae and pupae of Hoplia philanthus		HbCLO51, SgBE, S. scarabaei were highly virulent to the third-instar larvae	Ansari *et al*., 2008
H. megidis VBM30				
H. indica				
S. scarabaei				
S. feltiae				
S. arenarium				
S. carpocapsae Belgian				
S. glaseri Belgian				
S. glaseri NC				
S. scarabaei	2nd and 3rd instar grub of *Phyllophaga georgiana*		76–100% control	Koppenhofer *et al*.,2008
H. bacteriophora				
H. zealandica				
S. glaseri NJ	*T. baal*	strawberry	Virulent to all the stages	Atwa, 2009
H. bacteriophora HP 88			virulent	
S. longicaudum BPS	chafer grub	peanut	95.7% control	Du *et al*.,2009
S. scarabaei	*Anomala orientalis*	turfgrass	77–100% control	Koppenhöfer & Fuzy, 2009
S. feltiae C76	*Melolontha melolontha*		53% control	Laznik *et al*., 2009
Entonem				
S. longicaudum BPS	chafer grub	peanut	95.7% population decrease	Liu *et al.*,2009
H. indica	chafer grub	peanut	95.7% control	Liu *et al*., 2009a; 2009b
H.bacteriophora GPS11	Popillia japonica		1st instar more susceptible	Power *et al.*,2009
S. sp.	*Brahmina coriacea*	Potato	effective	Sharma *et al*., 2009
H.sp.				
S. carpocapsae	*Polyphylla olivieri*		Natural pathogen	Karimi *et al.*, 2010
S. feltiae B30	*Leptinotarsa decemlineata*		Control larvae, not eggs & adults	Laznik *et al*., 2010
Entonem				
S. riobravis	Phyllophaga bicolor		12.50% mortality	Liliana *et al*.,2010
S. carpocapsae All			22.92%	
S.sp.-SNI			10.42%	
S. arenarium			16.67%	
S. feltiae-Sf1			66.67%	
S. feltiae-Sf2			33.34%	
H. bacteriophora-Hb1			89.58%	
H. bacteriophora- Hb2			93.75%	
H. bacteriophora- Hb3			64.58%	
H. indica MP17	*2nd instar grub of* Popillia japonica			Maneesakorn *et al*., 2010
H. indica MP111			virulent	
H. sp. MP68				
S. minuta MP10				
H.bacteriophora	Eggs, Pupae and Adults of *Maladera Insanabilis*		Adults more susceptible	Bhatnagar,2011
S. lamjungense LMT5	*Holotrichia longipennis*		Higher mortality	Khatri-Chhetri *et al.,* 2011
S. lamjungense SS4				
S.everestense DKP4				
S.abbasi CS1				
S.sp KL1				
H.indica CK2				
H.indica CK6				
H. georgiana D61	*Popillia japonica*		55% to 95% mortality	Morris & Grewal , 2011
Steinernema sp. R54, R45, and FC48				
S. carpocapsae All and D60				
H. georgiana D61	adult of Popillia japonica		Cause mortality	
S. sp. R54, R45, and FC48				
S. carpocapsae All and D60				
H. bacteriophora D98 and GPS11				
H. indica ICRI EPN-18	cardamom root grub	*Elettaria cardamomum*	72 - 99.6 % reduction	Varadarasan *et al*., 2011
H.bacteriophora	*Anomala orientalis, Cyclocephala borealis*		somewhat resistant hosts	Ebssa *et al*., 2012
S. glaseri	*Popillia japonica*		susceptible hosts	
S. scarabaei	*Popillia japonica*		highly susceptible host	
S. longicaudum X-7	*Holotrichia parallela, H.oblita*	*Arachis hypogaea*	Higher grub reduction	Guo *et al*., 2013;2015
H.bacteriophora H06				
H.bacteriophora S. glaseri	*Polyphylla adspersa*		EPN-triggered encapsulation in larvae	Alvandi *et al*., 2014
H.bacteriophora	3rd instar Cyclocephala lurida		virulent	Wu *et al.,* 2014
H. megidis				
S. feltiae				
S.riobrave				
H.indica NBAII-104	Second instar grub of *Leucopholis lepidophora*		62-95% mortality	Bharathi & Mohite, 2015
S. carpocapsae NBAII-04			46.01-77.36% mortality	

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H.indica	*Phyllognathus dionysius*		52.5-85.5%	Rathour *et al*.,2015
H.indica NBAII-104	2^{nd} instar grub of *Holotrichia serrata*		virulent	Supekar & Mohite , 2015
S. carpocapsae NBAII-04				
H. bacteriophora	*Lepidiota mansueta*		parasitic	Devi *et al*., 2016.
S.sp.				
H. indica	*2^{nd} instar grub of* Holotrichia consanguinea		25-100% mortality	Patil *et al*.,2016
S.abbasi			20-80%	
S. carpocapsae	*Leucopholis burmeisteri*		100% mortality	Rajkumar *et al*., 2016
S. rarum CUL	L_1,L_2,L_3 of *Diloboderus abderus*	Triticum aestivum	95% mortality of L_1, 45% mortality of L_2	Eleodoro *et al.,* 2017
H.bacteriophora SMC				
Hexamermis popilliae	*Popillia japonica*		parasite	Mazza *et al.,* 2017
H.bacteriophora	*Popillia japonica*		57% to 100%	Marianelli *et al.,* 2017
S.carpocapsae			3% to 77%	
H. bacteriophora ItH-LU1			44% to 93%	
H. indica-infected *Galleria* cadavers	white grub	sugarcane	69.1% reduction of population	Mohan *et al*.,2017
H.bacteriophora Nematop®	3^{rd} instar grub of *Popillia japonica*		90% mortality	Paoli *et al*.,2017
H. indica	*Holotrichia consanguinea*	Sugarcane	56.43% mortality	Paschapur *et al*., 2017
S.feltiae	third-instar grubs of Popillia japonica		Modest efficacy in the loamy sandy soil	Helmberger *et al*., 2018
H.bacteriophora				
H.bacteriophora Rwanda14-N-C4a	*Anomala graueri*		18 to 22%	Kajuga *et al.,* 2018
H.bacteriophora H06			18 to 22%	
S. carpocapsae All			18 to 22%	
S. carpocapsae RW14-G-R3a-2			34 - 58%	
S.sp. RW14-M-C2a-3			2 to 6%	
S.sp. RW14-M-C2b-1		potato	96 % reduction	
S. longicaudum X7			82 up to 95%	
H. indica	Leucopholis lepidophora	Arecanut	promising	Patil & Vijayakumar,2018
S.abbasi				
H.indica DSM78	*Holotrichia serrata*		43.5-77% reduction in population	Sankaranarayanan *et al*., 2018
H. indica	*Leucopholis lepidophora*		48% mortality	Shewale &Mohite, 2018
S.abbasi	*Holotrichia serrata*		50% mortality	Aasha *et al*., 2019
H. indica	white grub	groundnut	73.34 % mortality	Kamaliya *et al*., 2019

A number of biocontrol agents, viz. predators, parasites, and the micro-organisms of this pest have been reported by various workers (Veeresh, 1973; Yadava *et al*., 1973; Jayaramaiah and Veeresh, 1983; Vyas *et al*., 1990; Nehru *et al*., 1991). None of them, however, could bring down grub populations to non-pest levels within a short time. One of the promising biological control agents is the entomopathogenic nematodes for the management of white grub populations. Entomopathogenic nematodes (EPNs) have been described from 23 nematode families. Out of these Steinernematidae and Heterorhabditidae have received the most attention because they possess many of the attributes of effective biological control agents (Kaya and Gaugler, 1993; Grewal *et al*., 2005) and have been utilized as classical, conservational, and augmentative biological control agents. Extensive research has demonstrated both their successes and failures for control of insect pests of agricultural crops, ornamentals, lawn and turf (Shapiro-Ilan *et al*., 2002; Georgis *et al*., 2006; Georgis and Poinar, 1994). Glaser and Fox (1929) found a nematode infecting grubs of the Japanese beetle, *Popillia japonica*, at the Tavistock Golf course near Haddonfield, New Jersey. Steiner described as *Neoplectana* (= *Steinernema*) *glaseri* (Steinernematidae). Glaser was the first to cultivate an entomopathogenic species on solid media axenically and the first to conduct the field experiments with cultured nematodes against Japanese beetle (Glaser and Farrell, 1935). When applied under favorable conditions these nematodes have been as effective as chemical insecticides against *P. japonica* (Georgis and Gaugler, 1991; Gaugler *et al*., 1992). Nematode efficacy against white grubs varies considerably with nematode species/strain and white grub species as well as larval stage (Table1). Species such as *E. orientalis*, *R. majalis*, *Cyclocephala* spp. and *M. castanea* appear to be less susceptible to the commonly used nematode species and strains such as *Heterorhabditis bacteriophora* Poinar and *Steinernema glaseri* Steiner (Simard *et al*., 2001). White grubs are among the more difficult insects to control with EPNs because they have developed various morphological and behavioral barriers to infection (Klein *et al*., 2007). Selection of an EPN for control of a particular pest insect is based on several factors that include the nematode's host range, host finding strategy, tolerance of environmental factors and their effects on survival and efficacy (temperature, moisture, soil type, exposure to ultraviolet light, salinity and organic content of soil, means of application and agrochemicals) (Gerritsen *et al*.,1997). Attempts to use nematodes for inundative white grub control were triggered by the commercialization of entomopathogenic nematodes especially by the development of liquid culture for *Heterorhabditis* spp. Despite considerable efforts in research and development, nematode use against white grubs is limited. The major reason for this has been competition from chemical insecticides that are easier to use and generally cheaper. In Japan, *S. glaseri* has been successfully marketed for white grub control because of limitations on the use of chemical insecticides on golf courses, similarly, in Germany, where no insecticides are available for white grub control on golf courses, a product based on *H. bacteriophora* is commercially available.

Conclusion

Entomopathogenic nematodes offer an environmentally safe and IPM compatible alternative to chemical insecticides for the control of white grubs (Klein, 1993). In order to build a conservation approach for the use of EPNs, factors affecting the natural populations and their biology must be understood. Although nematode persistence can vary in laboratory and field conditions, basic data on their longevity will be more helpful in choosing the best match of EPN for a particular target white grub species. The potential for improving nematode utility in the future (reduced production costs, more pathogenic nematode species and strains, and better understanding of white grub-nematode interactions) appears promising. Combination of nematode and other insect pathogens may provide a higher degree of efficacy against white grub.

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