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RESEARCH ARTICLE

BIOCONTROL POTENTIAL OF ENTOMOPATHOGENIC NEMATODES AGAINST TERMITE

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ABSTRACT

Termites cause economic losses by directly destroying both living and dead vegetation. Use of chemicals is a common mean to control termite which cause danger to humans and the environment. Therefore, there has been great interest in finding other methods, especially biological control, of controlling termites and reducing the use of chemicals. Many organisms have been identified as being able to kill termites. This review outlines the potentials of entomopathogenic nematodes in termite management.

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INTRODUCTION

Termites are classified at the taxonomic rank of infra order Isoptera, or as epifamily Termitoidae within the order Blattodea. Termites are found in almost all landmasses except for Antarctica. Their colonies range in size from a few hundred individuals to several million individuals. About 3,106 species are currently described. In Asia, there are 435 species of termites. Many termite species pose significant problems as pests in agriculture, forestry and urban ecosystems. Termites divide labour among castes consisting of sterile male and female workers and soldiers. All colonies have fertile males called kings and one or more fertile females called queens. Each individual termite goes through an incomplete metamorphosis that proceeds through egg, nymph, and adult stages. There are three ecological groups of termites: dampwood, drywood and subterranean. Subterranean termites live in widely diverse areas, mostly feed on dead plant material and cellulose, generally in the form of wood, leaf litter, soil, or animal dung. Subterranean termites *Reticulitermes flavipes* live in colonies composed of workers, soldiers and reproductives. The workers feed on wood and can cause serious damage to wooden structures (Edwards and Mill, 1986). Another subterranean termite *Odontotermes obesus* are one of the most dangerous and difficult to manage insect pests of agricultural crops in loamy and sandy loam soils (Peterson *et al.,* 2006; Potter, 2011). Termites cause estimated losses of US$22 billion annually across the globe (Govorushko, 2011). In India, termite infestation is a devastating problem in the wheat, maize and pearl millet and other field crops and orchards leading to complete loss of the crop in certain cases. The most common means of termite control is a periodic spraying with chemical insecticides or injection of soil surrounding structures with large quantities of insecticides. But use of chemicals around homes and gardens poses direct danger to humans and the environment. Due to increasing concerns about these side effects, there has been great interest in finding other methods, especially biological control, of controlling termites and reducing the use of chemicals (Grace 2003). Biocontrol agents like predators, parasitoids and pathogens have been tested to suppress termite populations. Characteristics of the colony, such as a protected or underground location are likely to limit the impact of predators and parasitoids on subterranean termites. Pathogenic organisms, such as viruses, bacteria, Protozoa, and most fungi, have shown little promise for use in biological termite control.

Entomopathogenic nematode as a biocontrol agent: Entomopathogenic nematodes, as a group of biological control agents, continue to attract a great deal of attention. Of the nearly 40 nematode families that are associated with insects, only two of these families, Steinernematidae and heterorhabditidae, are widely used in biological control (Gaugler and Kaya 1990). These nematodes are obligate insect parasites, associated with bacterial symbionts, *Xenorhabdus*

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Table 1. Nematodes found to be associated / pathogenic in termite

Nematodes	Termite spp.	Achievements	References
Diplogaster aerivora	*Leocotermes lucifugus*	Associated, insect death	Merrill & Ford,1916
D. aerivora	*Reticulitermes flavipes*	Associated, insect death	Banks & Snyder, 1920
mermithid	*Thoracotermes brevinotus*	parasitic	Hegh,1922
mermithid	*Cornitermes orthocephalus*	associated	Ruttledge, 1925
Termirhabditis fastidiosus	*Reticulitermes flavipes*	parasitic	Massey,1971
Rhabpanus ossiculum			
Neoaplectana carpocapsae	*Coptotermes formosanus*	96% mortality	Fuiji, 1976
Steinernema. carpocapsae	*Coptotermes*, *Nasutitermes* and *Termes*	effective	Poinar, 1979
Heterorhabditis spp.	*Mastotermes darwiniensis,*	control	Bedding & Stanfield, 1981
N.carpocaisae	*Zootermopsis* sp., *Reticulitermes sp.*	95% mortality	Georgis *et al*.,1982.
H. sp.	*Glyptotermes dilatus*	Control	Danthanarayana & Vitarana, 1987
S.feltiae	*Reticulitermes tibialis*	Not effective	Epsky & Capinera, 1988
S. feltiae Breton *S. feltiae* All *S.bibionis* *H.heliothidis*	*Reticulitermes* spp	control	Mauldin &Beal, 1989
S. carpocapsae	*Reticulitermes* spp.	≥ 80% mortality	Poinar & Georgis, 1989
H. bacteriophora			
S. carpocapsae	*Nasutitermes costalis,* *Reticulitermes flavipes*	effective	Trudeau, 1989
Chroniodiplogaster aerivora	*Reticulitermes tibialis*	associated	Poinar ,1990
S. feltiae	Coptotermes formosanus	susceptible	Wu *et al*.,1991
Neosteinernema longicurvicauda	*Reticulitermes flavipes*	parasitic	Nguyen &Smart, 1994
H.sp. *S*.sp.	*Reticulitermes santonensis,* *Zootermopsis*	susceptible	Samarasinghe, 1996
S. carpocapsae	*Reticulitermes flavipes* , *Coptotermes formosanus*	effective	Wang *et al*.,2002
S. riobrave			
H. bacteriophora			
H. indica			
Rhabditis sp.	*Reticulitermes flavipes*	67.9% parasitized	Wang *et al*.,2002
	Reticulitermes virginicus	38.8% parasitized	
	Coptotermes formosanus	3.3% parasitized	
S. carpocapsae BJ	*Odontotermes formosanus*	effective	Zhu,2002
S. feltiae Dtio			
S. longicadam D-4-3			
H.bacteriophora E-6-7 Mountain Tai NO.1			
Poikilolaimus ernstmayri	*Reticulitermes lucifugus*	associated	Sudhaus & Koch, 2004
H.bacteriophora	*Heterotermes aureus*	Not effective in field level	Weeks & Baker, 2004
S. carpocapsae			
Rhabditis rainai	*Coptotermes formosanus*	associated	Carta & Osbrink, 2005
Caenorhabditis sp.	*Anacanthotermes turkestanicus*	associated	Handoo *et al*.,2005.
S. carpocapsae	*Coptotermes formosanus,* *C. vastator*	effective	Mankowskia *et al*., 2005
H. indica			
Chroniodiplogaster formosiana	*Odontotermes formosanus*	associated	Poinar *et al*.,2006
S. riobrave 355	*Reticulitermes flavipes*	Low mortality	Yu *et al*.,2006
S. riobrave 355 *S. carpocapsae* Mexican 33	*Heterotermes aureus* , *Gnathamitermes perplexus,*	> or = 80% mortality	
S.feltiae UK76	*Reticulitermes flavipes*	Low mortality	
H.bacteriophora HP88	*Reticulitermes flavipes, Heterotermes aureus* , *Gnathamitermes perplexus*	Cause mortality	
S. carpocapsae	*Coptotermes curvignathus*	effective	Hiranwrongwera *et al*., 2007
S.carpocapsae	Zootermopsis angusticollis	reduce susceptibility	Wilson-Rich *et al*., 2007
S. riobrave	Psammotermes hybostoma	control	Ibrahim & Abd El-Latif, 2008
S.carpocapsae			
H.sp.			
H.bacteriophora			
Oigolaimella attenuate	*Reticulitermes*	associated	Von Lieven & Sudhaus, 2008
S. riobrave 355	*Heterotermes aureus*	effective	Yu *et al*., 2008
S. carpocapsae Mexican 33		effective	
S.feltiae UK76		Not producing progeny	
H.bacteriophora HP88		effective	
rhabditids, diplogastrid, *Rhabditis rainai* *Poikilolaimus floridensis*	*Cryptotermes cavifrons, Incisitermes snyderi, Neotermes jouteli, N. castaneus, Prorhinotermes simplex, Reticulitermes flavipes*	associated	Scheffrahn *et al*., 2009

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Pseudaphelenchus yukiae	*Cylindrotermes macrognathus*	associated	Kanzaki *et al*.,2009
Pelodera termitis	*Anacanthotermes turkestanicus*	associated	Carta *et al*.,2010.
S. riobrave 3-8b	Heterotermes aureus, Reticulitermes flavipes, Coptotermes formosanus.	Cause mortality	Yu *et al*., 2010
S. riobrave 7-12			
S. riobrave TP			
S. riobrave 355			
H. baujardi	*Psammotermes hypostoma, Anacanthotermes ochraceus*	Susceptible	El-Bassiouny& Randa,2011
H. indica			
Poikilolaimus carsiops	*Neotermes koshunensis*	associated	Kanzaki *et al*.,2011
S. glaseri	Reticulitermes flavipes	100% mortality	Murugan &Vasugi, 2011
H.bacteriophora	Macrotermes sp.	Photorhabdus luminescens caused 98% mortality	Shahina *et al*.,2011
S. carpocapsae	*Reticulitermes flavipes*	effective	Manzoor, 2012
H.bacteriophora			
Pseudaphenchus sui	*Coptotermes formosanus*	associated	Kanzaki *et al*.,2014
P. scheffrahni	*Nasutitermes takasagoensis*		
P. vindai	Panamanian termites		
Pusa Nemagel	*Odontotermes obesus*	48-78% Reduction in population	Rathour *et al*.,2014
H. indica Ayogbe1	*Macrotermes bellicosus, Trinervitermes occidentalis*	effective	Zadji *et al.*,2014
H. sonorensis Azohoue2			
H. sonorensis Ze3			
S. sp. Bembereke			
Twenty-nine Beninese isolates of *H.sonorensis*	*Macrotermes bellicosus*	effective	Zadji *et al*., 2013;2014
one local isolate of *H. indica*			
H. indica Ayogbe1	*Trinervitermes occidentalis, Macrotermes bellicosus*		Baimey *et al*., 2015
H. sonorensis Azohoue2		63.2% termite mortality	
H. sonorensis Ze3			
S. sp. Bembereke			
H. indica	*Microtermes* spp	effective	Mohan *et al*.,2016.
S. abbasi			
S. siamkayai	*Reticulitermes flavipes, Odontotermis hornei*	effective	Razia & Sivaramakrishnan, 2016
S. pakistanense			
H.indica			
S.karii	*Coptorermes formosanus*	effective	Wagutu *et al.*,2017
H.bacteriophora	*Odontotermes obesus*	effective	Devi *et al*.,2018.
S. sp			
Agamomermis termitivoratus	*Reticulitermes flavipes*	Parasitic	Poinar *et al*.,2019

spp. and *Photorhabdus* spp. (Forst *et al*., 1997).The infective juvenile stage of the nematode is a free living stage that remains in the soil until it can invade the body of a potential host on contact . After infection of the insect host, symbiotic bacteria are released into the insect hemocoel, causing septicemia and death (Kaya and Gaugler, 1993). Hundreds of different species from most orders of insects are susceptible to various entomopathogenic nematodes under laboratory tests. Nematodes have the advantages of being easy to apply, compatible with many pesticides and other biocontrol agents. Termites live and forage in habitats that are moist, cool, and without direct sunlight. These environmental conditions are ideal for the survival and movement of entomopathogenic nematodes, and, therefore, provide the basis for the interest in their role in control of termites (Chouvenc *et al*., 2011). Various species of diplogaterid and rhabditoid nematodes have been found in natural populations of termite (Merrill and Ford, 1916; Banks and Snyder, 1920; Poinar, 1975; Poinar, 1990; Wang *et al*., 2002; Poinar *et al*., 2006). Mermithid parasitism of termites is a rare occurrence. The earliest record was by Hegh (1922) who reported an unknown mermithid attacking the European termite, *Thoracotermes brevinotus*. Ruttledge (1925) reported a mermithid in *Cornitermes orthocephalus* in Brazil.

Bioefficacy of entomopathogenic nematodes against termite: Entomopathogenic nematodes showed effectiveness against subterranean termites in the laboratory, but did not cause colony elimination in the field with *Reticulitermes flavipes* (Mauldin and Beal, 1989), *R.tibialis* (Epsky and Capinera, 1988), *Coptotermes formosanus* (Tamashiro, 1976).The reasons suggested were termite social behavior like walling off dead termites and avoiding foraging in nematode infested areas (Reese, 1971; Fujii, 1975). Insect susceptibility to entomopathogenic nematodes varies among insect species and is influenced by nematode species, strain, and an assembly of abiotic and biotic factors (Kaya and Gaugler, 1993) (Table 1).Formosan termites (*Coptotermes formosanus*), subterranean termites (*Reticulitermes* spp., *Gnathamitermes perplexus* and *Heterotermes aureus*, *Mastotermes* spp.), livewood termites (*Glyptotermes dilatatus* and *Postelectrotermes militaris*) and dampwood termites (*Zootermopsis angusticollis*) have been shown to be susceptible to EPNs both in the laboratory and under field conditions (Yu *et al*., 2006). Wilson-Rich *et al*., (2007) showed that *S.carpocapsae* cause dose dependent mortality of the dampwood termite (*Z. angusticollis*) and the termites increased their frequency and duration of allogrooming, vibratory displays, abdominal tip raising and self-scratching in response to nematode infection. Populations of the dampwood termite *Glyptotermes dilatatus* that form colonies have been successfully managed in tea plantations on SriLanka with *Heterorhabditis* sp. (Dhanthanarayana and Vitarana, 1987). Likewise, nematodes showed potential in eliminating infestations of dampwood termite, *Neotermes rainbow in* the unbranched trunks of coconut palms, but their effectiveness was less in branched trees of *Citrus,* cocoa or *Swietenia macrophylla* (Lenz and Runko, 1992; Lenz *et al*., 2000). These branches allowed parts of the population occasionally to retreat into them and block off the connection to the main trunk which had received injections of infective nematode larvae, thus preventing the spread of the nematodes to all areas occupied by a colony. In Australia, *Heterorhabditis* sp. have also been used to eliminate residual populations of active infestations by subterranean *Coptotermes* sp. trapped in buildings after a perimeter barrier with a repellent chemical has been applied. Infective nematode larvae will kill the trapped termites and move from the site of application inside the building to the nest of the colony. The reported temperatures of above 30ºC in the centre of nests of *Coptotermes* where reproductives and brood are housed prove lethal for the nematodes. Hence the impact with currently used isolates of the nematode may never go beyond killing termites in the outer parts of the nest or within the tunnel system in the soil, although some cases of apparent colony elimination have been reported. Different isolates or species of entomopathogenic nematode species that are tolerant to higher temperatures are required for control of subterranean termite species with central compact nests .After injections of larvae of a *Heterohabditis* isolate from tropical Australia into eucalypt trunks in which *Mastotermes darwiniensis* foragers were active, masses of dead termites were found. However, due to the complex biology of *M. darwiniensis*, including its diffuse nest system, the presence of multiple sets of reproductives, large territory size and simultaneous use of many feeding sites, it remained uncertain what the impact of the treatment on the colonies as a whole was .

Conclusion

Diseased termite colonies are rarely encountered in the field, although many a time even a healthy termite colony will harbour some pathogenic organisms. However, sanitary measures within a colony, such as allogrooming, removing, feeding on cadavers, and the production of antibiotics ensure that disease outbreaks are kept in check. Only when colony vigour is weakened by age or chemical control measures, can epizootics readily develop and colonies may perish from diseases. Inundative release of these nematodes will only be useful for short-term protection and local control until means are developed to enhance survival and pathogenicity in systems such as bait matrices (Wang *et al*., 2002). Some of the modern termiticides are even known to act synergistically with soil micro-organisms to cause a more rapid decline in termite populations. Termites stressed by sublethal doses of chemical or pathogens probably are more susceptible to entomopathogenic nematodes. A combination of nematodes with other biocontrol agents or chemicals may improve their control over termites. Nematode and neem extract (4.0% NSKE + 600 infective juvenile *Steinernema glaseri*) can be used for subterranean termites *Reticulitermes flavipes* (Murugan and Vasugi, 2011). *H.bacteriophora* and *S.carpocapsae* alone had no significant effect on termite mortality but there was synergism between imidacloprid and nematodes species that caused more than 50% mortality in most treatments within all three colonies of *Reticulitermes flavipes* (Manzoor, 2012). Based on ecological knowledge of termites as well as biocontrol agents and minimization of environmental impact of treatments, integrated pest management (IPM) strategies should be adopted for termite problem. More study on nematode biology, screening for more infective nematode species, strains, or application techniques will provide new valuable information on possible use of nematodes for termite control (Wang *et al*., 2002).

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