Management of Dipteran pests through Entomopathogenic Nematodes

Abstract:

Dipteran insects are most destructive agricultural pests, They are vectors of many diseases. EPNs have been reported as a potential biocontrol agent against many Dipteran insect pests. However, several biotic and abiotic factors along with method of application influence the bioefficacy of this organism against Dipteran insects.

***Key words*:**Entomopathogenic nematodes(EPNs), Dipteran insect, biocontrol agent, Application method

Introduction

The order Diptera is a successful group of insects with greatly diversified number of insects with more than 125,000 species. They are coevolved in association with plants and animals.They are small to medium sized insects with soft bodieswith a single pair of wing, commonly known as flies.Besides being agricultural pests, they are vectors of many diseases.Some of them are fruit flies (Tephritidae and Drosophilidae), leaf miners (Agromyzidae) or gall former (Cecidomyiidae).Larvae of some Dipteran pests are predatory in nature. Some are obligate parasites of mammals and livestock.Much effort has been made to control this pest through chemical treatment.The application of pathogenic organisms has been advocated as an ecofriendly control method for insect pests.Entomopathogenic nematodes(EPNs) offer an ecofriendly and IPM compatible alternative to chemical insecticides for the control of Dipteran insects.

Habitat of Dipteran insect

Maggots or grubs are the larval stage of the order Diptera are the most important agriculturally ; they are found in many habitats viz., in any kind of water,soil, in plant tissue or beneath bark or stones,in organic matter. Adults also feed on plant or animal juices or other insects.

Management

Insecticides are commonly used to control of feeding and disease transmission.However, some new technologies like using of novel insecticides,repellants,sterile insect technology have been advocated for the management of Dipteran pests. However, growing resistance against some

insecticides along with environmental pollution and the lack of effective biological control alternatives make using Entomopathogenic nematodes (EPNs) against many insect pests of agricultural crops.

Entomopathogenic nematodes(EPNs)

Entomopathogenic nematodes (EPNs) are the obligate parasites of insect pests. The 3rd stage juveniles are the infective stages that are free-living, non-feeding under the families of Steinernematidae and Heterorhabditidae). Members of both families are associated with mutualistic bacteria of the genera *Xenorhabdus* (for Steinernematidae) and *Photorhabdus* (for Heterorhabditidae). IJs locate the host by detecting the insect excretory products, carbon dioxide levels, temperature gradients and movement of the host. IJs penetrate the host through natural openings, mouth, anus or spiracles, or throughthe cuticle . Once they enter the hemocoel, they release the bacteria which multiply and kill thehost within 24-48 hrs. In field application, a concentrationof 2.5–5 × 10^9 IJs/ha are recommended to give effectivecontrol.ENPs have a great potential to be used inintegrated pest management programs. However, the susceptibility of insect pests varies depending on the selectivity and applied rates of EPN species. Temperature, moisture, aeration and soil type, the species of EPN, stage of target insects and soil fauna are important factors affecting the bioefficacy of EPNs(Koppenhofer. et al., 2020).

Control potentialities of EPNs(Table.1)

Fungus gnat larvae damage cuttings of various ornamentalsand reduce root weight and vigor of a wide rangeof ornamentals. Larval feeding is believed to predispose theplants to attack by pathogenic fungi. Determining an appropriate concentration, application timing and temperature is crucial in the cost effective control of fungus gnats in greenhouse production. A single application of *S. feltiae*(2.5×10^6 IJs/m^2) against the second, third, and fourth instar larvae and at temperatures below 25^{o}C produced consistently high level of control. The potting media affect the survival and infectivity of the nematodes.

Leafminers, *Liriomyza* spp. are among the major pests offield and glasshouse-grown vegetables and ornamental cropsworldwide. Larval mining and adult stippling caused by theleafminers destroy leaf mesophyll, decrease the level of photosynthesis,and allow entry of plant pathogens. The use ofvarious species and strains of steinernematids and heterorhabditidsagainst soil-inhabiting prepupae and pupae stagesof leafminers produced variable and inconsistent results(Head and Walters, 2003). In general,to achieve reliable control, optimum spray volume is

essentialto allow the nematodes to come in contact with the larvalstages. Maintaining high relative humidity (above 90%)in the greenhouse and/or moisture on the plants for at least6–8 h after nematode applications is critical for successfulcontrol .The best control of *Liriomyzatrifolii* wasachieved with 2–4 weekly applications of S. carpocapsae or S. feltiae at 1×10^6 IJs/m^2 against the second and thethird instars larvae.

Sciarid flies that are found associated withmushrooms throughout the world, *Lycoriellaauripila*(Fitch), *Lycoriellamali* (Fitch) and *Lycoriellasolani*Winnertz,are the most significant species adversely affectingmushroom cultivation . Larvae feed on the compost and destroy itsstructure and water retention capacity, which in turn inhibitsmycelial colonization causing a significant reduction inmushroom yield. The use of appropriate nematode rates, application site,and application timing for the cost effective management ofmushroom flies is economically important for mushroomgrowers. Several concentrations ranging from 1.5- 3.0×10^6 S. feltiae/m^2 have been tested to achieve satisfactorycontrol of sciarid infestations.

The phorid fly, *Megaseliahalterata* (wood) causes considerable problems formushrooms. Adults are very strongly attracted to compostor casing in which spawn is running. Larvae feed on mycelia, generally in lowerlayers of compost. Adult flies become most problematicwhen they enter the crop soon after spawn run.*S. feltiae* can infect phorid flylarvae in mushroom production houses.

The cabbage maggot, *Delia radicum* (L.), is a cosmopolitanpest of radish, rutabaga and other cole crops. The larvae hatch and tunnel into root tissue andcan reduce yield through plant stunting or death.*S. carpocapsae* and *S. feltiae* have been the most commonlyused species in field evaluations. Timing and conditions for nematode applicationshave to optimal because *D. radicum* larvae are only in thesoil for a brief period.

The house fly, *Musca domestica* (L.), is common in animal-rearing farms. Larvae develop in manure and other organic matterand the life cycle can be completed in as little as7-10 days depending on temperature.Inlaboratory assays, nematodes that were applied to moist filterpaper or animal manure were effective in killing this insectwith the most susceptible stages being second and thirdinstars and adults Baits treated with either S. feltiae orH. megidis provided significantly greater control of theadult population compared tosynthetic chemicals.

Among thefruit fly species, the oriental fruit fly, *Bactrocera dorsalis*(Hendel) is an important insect pestof citrus fruits. Both third instar larvae and pupae are biological stages that persist in

the soil until adult emergence. Several studies have been carried out under laboratory and field conditions showing how ENs can be applied within an area-wide integrated pest management approach to control fruit fly species in orchards and backyard fruit trees.

The infective stages ofnematodes,*S. carpocapsae*are sprayed on *Liriomyza*-infested plants. The IJs enter the leafmine via thepunctures created by female flies during egg laying or hostfeeding. Upon contact with the host larva, nematodes arelikely to infect the insect via the anus rather than the mouth,but not through spiracles. Evidence from various studies suggests a requisite ambient relative humidity of greater than 90% for nematodes. However, efficacy varies dependingon pest species, development stage of the pest, concentrationsof nematodes and environmental conditions(Abbas, 2022).Environmental conditions are critical to the survival andvirulence of nematodes. entomopathogenic nematodes should be formulated and applied to optimize their performance. The choice of application method may influence how nematodes should be formulated for best results. Infective stage juveniles (IJ) may be applied to foliage using common agrochemical equipment, including hand-held pressurized sprayers, mist blowers, electrostatic or spinning disc systems and aircraft mounted atomizer sprayers.

Table.1. Parasitism of entomopathogenic nematodes against dipteran insects.

Entomopathogenic nematodes	**Insects**	**Infectivity(%)**	**references**
Heterorhabditisbacteriophora, H. indica, Steinernema asiticum, S. corpocapsae , S. glaseri	Oriental fruit fly larvae (*Bacterocera dorsalis*)	94.97 %	Aatif *et al*.,2019;2023
S. feltiae S. corpocapsae H.bacteriophora	Olive fruitfly pupae (*Bactroceraoleae*)	80%	Torrini et al.,2017
S. feltiae (SN), *S. carpocapsae* (All), *S. riobrave*, *S. glaseri* (NC), *H.bacteriophora H. marelatus*	The olive fruit fly, third-instar larvae (*Bactroceraoleae*)	19.1-67.9%	Sirjani*et al*.,2009
H.bacteriophora, *H. indica*, *H.marelatus*, *H.zealandica* , *S. feltiae*	late third larval instar and pupal stages of *Queensland fruit fly (Bactroceratryoni)*	caused significant larval mortality	Aryal et al.,2022
S. feltiae, *S.carpocapsaeH.bacteriophora*	Third larval instar of *Queensland fruit fly*	caused significant	Langford et al.,2013

	(Bactroceratryoni)	larval mortality	
S. feltiae	peach fruit fly, (*Bactrocerazonata*)	100%	Mahmoud. 2007
H.bacteriophora, *H. megidis*, *H. georgiana*, *H. floridensis*, *H.indica*, *S.carpocapsae*, *S. riobrave*, *S. feltiae*, *S. rarum* , *S. glaseri*	larvae, pupae and adultsof*BactrocerazonataB. dorsalis*	58.50-93.06%	Usman et al.,2021; Wakil et al.,2022
H.bacteriophora, *H.indica*, *S.carpocapsae*, *S.glaseri*.	3rd larval instar of house fly (*Musca domestica*)	43.3-10%	Bream *et al*.,2018
S.feltiae SN, *S. feltiae* UK *S. carpocapsae* (All) *H.bacteriophora* (NC) *H.megidis*	*Lycoriellaauripila*, *L. mali*, *L. solani* *Megaseliahalterata* Fungus gnats (*Bradysiacoprophila* , *B. differmis*)		Grewal & Richardson, 1993; Harris et al., 1995;Scheepmaker*et al*., 1998; Jagdale *et al*., 2004,2007; Jess *et al*. 2005; Tomalak et al., 2005; Grewal,2007 Grewal & Georgis, 1998; Grewal,2007
Steinernema sp. *S. abbasi* *S. pakistanense* *H. indica*	*Megaseliasandhui*	13–33%	Lamba et al. (2008)
H. bacteriophora, *S. carpocapsae*, *S. feltiae*, *H. indica*, *S.longicaudum*	chive maggot (*Bradysiaodoriphaga*)		Bai et al., 2016; Wu et al.,2017
S. yitgalemense *S. feltiae* *S. jeffreyense* *S. khoisanae*	*Bradysia impatiens*	52-87%	Katumanyane (2017)

Steinernema sp. *H. indica* *H. zealandica* *H. bacteriophora* *H. noenieputensis* *S. carpocapsae* All, *S. feltiae* MG-14 *Heterorhabditis* sp.UK 211	*Liriomyzatrifolii* *L.huidobrensis* *L. bryoniue*	24-69% 82%	Hara et al., 1993; LeBeck et al., 1993; Sher et al., 2000; Head &Walters, 2003; Tomalak et al.,2005; Williams & Walters,2000 Williams &Macdonald , 1995
S. riobrave, *S. carpocapsae,* *S. feltiae*	fruit flies (*Rhagoletisindifferens,* *Anastrephaludens*)		Yee and Lacey, 2003; Toledo et al., 2005
*S.carpocapsae*ALL *S. feltiae*SN , *S. riobrave*355 , *S. glaseri*VS , *H.bacteriophora*VS *H.indica*HOM1 *H.megidis*UK211	Pupal stage of the apple maggot (*Rhagoletispomonella*)	42.9-73.8%	Usman et al.,2020
H. bacteriophora, *H. marelatus,* *S.carpocapsae,* *S. feltiae*	European cherry fruit fly (*Rhagoletiscerasi*)	40-95%	Kepenekci et al., 2015
S.bicornutum, *S. carpocapsae,* *S. carpocapsae China, S. feltiaeH.bacteriophora*	European cherry fruit Fly (*Rhagoletiscerasi)*	54%	Koppler et al.,2003
H. bacteriophora UWS1 *H.bacteriophora,* *S. carpocapsae ,* *S.feltiae*	Crane fly (*Tipulapaludosa*)	28-65%	Ansari & Butt,2012; Oestergaard*et al*., 2006; Simard *et al*., 2006
S.feltiae	Cranefly larvae	13-90%	Ehlers

S.anomali *S.affinis*	(*Tipulapaludosa*)		&Gerwien, 1993
S.feltiae	Cranefly larvae (*Tipulapaludosa*, *Tipula oleracea*)	L1 susceptible stage	Peters &Ehlers,1994
S. riobrave *S. carpocapsae* *S. feltiae*	Mediterranean fruit fly or medfly (*Ceratitis capitata*)	50-100%	Gazit *et al*., 2000; Lindegren *et al*., 1990 Chergui et al.2019.
S.feltiae-SF-MOR9, *S. feltiae*-SF-MOR10 *H.bacteriophora*-HB-MOR7	Medfly (*Ceratitis capitata*)	80%	Mokrini et al.,2020
Heterorhabditis sp. RSC01 , *S.carpocapsae* ALL	Third-instars of Mediterranean fruit fly, (*Ceratitis capitata*)	26.7-96.7%	Rohde et al.,2010
S.carpocapsae ALL *H.amazonensis* JPM4	larvae and pupae of Mediterranean fruit fly (*Ceratitis capitata*)	50-80%	Rohde et al.,2020;
H.bacteriophora HB, *H. amazonensis* IBCB-n24, *S.carpocapsae* IBCB-n02, *S. rarum* PAM-25, *S. glaseri* IBCB-n47, *S. brazilense* IBCB-n06	pupae of Mediterranean fruit fly (*Ceratitis capitata*)	60-80%	Jean-Baptiste et al.,2021
H. noenieputensis, *H. indica* *H. bacteriophora* *S.yirgalemense*	Mediterranean fruit fly or Medfly, (*Ceratitis capitata,Ceratitis rosa)*		James et al.,2018
H.bacteriophora HP88 *S.carpocapsae* All	Full-grown larvae and pupae of Mediterranean fruit fly (*Ceratitis capitata*) Peach fruit fly, (*Bactrocerazonata*)	44.8-76.8%	Nouh &Hussein ,2014
H.bacteriophora AS1, *H. bacteriophora* HP88, *S.carpocapsae* ALL, *S. riobrave* ML29	Late third instars of the medfly, (*Ceratitis capitata*)	caused significant mortality	Shaurub*et al*.,2015
H.bacteriophora,*H.zealandica* *S. khoisanae*	Larvae, pupae and adults of (*Ceratitis capitata* , *Ceratitis rosa*)	caused significant mortality	Malan &Manrakhan, 2009
S.weiseri, *S. feltiae*09-31 *S. carpocapsae*	Last instar larvae of Mediterranean fruit fly or Medfly,	50-97%	Karagoz et al.,2009

H. bacteriophora	(*Ceratitis capitata)*		
S. feltiae	Third instars of Western	caused	Patterson &
S. carpocapsae	cherry fruit fly	significant	Lacey, 1999
S. riobravis	(*Rhagoletisindifferens*)	mortality	
H. bacteriophora			
H. marelatus			
Heterorhabditis sp. LPP17,	Third instar larvae of	90- 98.5%	Minas et
Heterorhabditis sp. LPP14	*(Ceratitiscapitata*)		al.,2016
H. baujardi LPP7			
S. feltiae	*Anastrephafraterculus*	75%	Foelkel et al.,2017
*H. bacteriophora*RS88 *S. riobravae*RS59	South American fruit fly, (*Anastrephafraterculus*)	20-51.3%	Barbosa-Negrisoli et al.,2009
H.bacteriophora	Caribfly		Heve et
H.indica	(*Anastrepha suspense*)		al.,2018
S.feltiae			
*H. taysearae*Azohoue2	Larvae and pupae of mango		Godjo et
(=H. sonorensis)	fruit fly (*Bactrocera*		al.,2021.
S.kandii	*dorsalis*)		
H.bacteriophora	The cabbage maggot	Caused	Sharifi-Far et
	(*Delia radicum*)	higher	al.,2018
		levels of	Chen et al.2003
		infection	
S. carpocapsae	*Drosophilamelanogaster*	Capable of	Pena et al.,2015
	larvae	infecting	
		and killing	
H. bacteriophora,	spotted wing	emergence	Garriga et
S. carpocapsae,	drosophila	of flies was	al.,2018
S. feltiae,	(*Drosophila suzukii*)	significantl	Hübner et
S. kraussei		y reduced.	al.,2017
H. bacteriophora	cucurbit fly	12-28%	Kamali et
S.carpocapsae	(*Dacus ciliates*)		al.,2013

Conclusion

Different species of entomopathogenic nematodes have distinct temperature niches for activity and may also respond differently to moisture availability.Therefore, isolation of local species and strains for use in specific environments are important prerequisite as biopesticides. Increased understanding of nematode biology, host range and concurrent advances in commercial production, storage and formulation, have led to nematode-based biopesticides safe alternatives to chemical insecticides. Successful use requires that the ecology of the target is matched to the activity of infective juveniles; in practice, targets are protected from environmental extremes,

applications are timed to coincide with susceptible host stages and favourable weather conditions and nematodes are able to rapidly locate and infect hosts. In addition to performance, factors including cost, availability, compatibility within integrated strategies and alternative options for organic growers will ultimately determine the extent to which nematodes are used against Dipteran insect pests.

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