Review on the 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.

Comment [Maryam1]: Please build up the abstract, it is very scanty

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

Introduction

Comment [Maryam2]: Give citation (reference) of all the information you provide and spell out the objectives of you review.

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

Comment [Maryam3]: This subsection is too scanty

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

Comment [Maryam4]: Management of what?
Remove; you should consider it as the statement of the problem

Insecticides are commonly used to control 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)

Comment [Maryam5]: Consider changing this to "the role of E

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, *Liriomyzaspp*. 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 thirdin stars 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.Nature of Parasitism of entomopathogenic nematodes against dipteran insects.

Entomopathogenic nematodes	Insects	Infectivity(%)	References
Heterorhabditisbacteriophora, H. indica, Steinernemaasiticum, 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%	Torriniet 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

Comment [Maryam6]: Italicize all et al

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

References

Comment [Maryam7]: Follow the APA format of referencing
Almost all the references are written inappropriately

Aatif HM., Afzal A., Idrees A., Mansha MZ., Shahid Hanif CM., Ali Y., Ikram K., Ullah MI., Sarkar SC., Alfarraj S., Li J. 2023. Entomopathogenic nematodes for the control of oriental fruit fly *Bacterocera dorsalis* (Diptera: Tephritidae). Journal of King Saud University–Science. 35:102428. https://doi.org /10.1016/ j.jksus. 2022.102428.

Aatif HM., Hanif MS., Ferhan M., Raheel M., Shakeel Q., Ashraf W., Ullah M.I., Ali S. 2019. Assessment of the entomopathogenic nematodes against maggots and pupae of the oriental fruit fly, *Bactrocera dorsalis* (Hendel) (Diptera:Tephritidae), under laboratory conditions, Egypt. J. Bio Pest Control 29, 51.https://doi.org/10.1186/s41938-019-0154-4.

Abbas MST.2022. Pathogenicity of entomopathogenic nematodes to dipteran leaf miners, house flies and mushroom flies. *Egyptian Journal of Biological Pest Control. 2:76.* https://doi.org/10.1186/s41938-022-00566-y

Abdel-Razek, A.S.; Abd-Elgawad, M.M.M. **2021.** Spinosad combined with entomopathogenic nematode for biocontrol of the Mediterraneanfruit fly (Ceratitiscapitata [Wiedemann]) on citrus. Egypt J. Biol. Pest Control, 31: 112

Ansari MA., Butt TM.2012. Evaluation of entomopathogenic fungi and a nematode against the soil-dwelling stages of the crane fly *Tipulapaludosa*. Pest Management Science .68: 1337-1344.

Aryal S., Nielsen UN., Sumaya NH., Wilson C., Riegler M. 2022. Virulence, penetration rate and reproductive potential of entomopathogenic nematodes from eastern Australia in Queensland fruit fly, *Bactroceratryoni*. Biol. Control169, 104871.

Bai GY, Xu H, Fu YQ, Wang XY, Shen GS, Ma HK, Ruan WB .2016. A comparison of novel entomopathogenic nematode application methods for control of the chive gnat, *Bradysiaodoriphaga* (Diptera: Sciaridae). J Econ Entoml 109(5): 2006–2013

Barbosa-Negrisoli CRC, Garcia MS, Dolinski C, Negrisoli JR, Bernardi D, Nava DE.2009.Efficacy of indigenous entomopathogenic nematodes (Rhabditidae:

Heterorhabditidae, Steinernematidae), from Rio Grande do Sul Brazil, against *Anastrephafraterculus*Wied (Diptera: Tephritidae) in peach orchards. J InvertebrPathol 102:6-13

Bream AS, Fouda MA, Shehata IE, Ragab SH. 2018. Evaluation of four entomopathogenic nematodes as biological control agents against the housefly, *Musca domestica* L. (Diptera: Muscidae).Egypt. Acad. J. Biolog. Sci. (A. Entomology) 11(1): 79- 89.

Chaneiko SM., de Brida AL., Bernardi D., Leite LG., Garcia FRM.2021. Biological activity of entomopathogenic nematodes on *Anastrephafraterculus*(Diptera: Tephritidae). Biosci. J., 37, e37047.

Chen S., Han X., Moens M.2003. Effect of temperature on the pathogenicity of entomopathogenic nematodes (Steinernema and Heterorhabditis spp.) to *Delia radicum*. BioControl. 48:713-724

Chergui S., Benzehra A., Boudjemaa K., Barkou H ., Karaca I.2019. Efficacy of Turkish isolate of *Steinernemafeltiae* (Rhabditida: Steinernematidae) in controlling the Mediterranean fruit fly, *Ceratitiscapitata* (Wiedemann) (Diptera: Tephritidae), under laboratory conditions. Egyptian Journal of Biological Pest Control, 29: 01-07

Ehlers RU., Gerwien A.1993. Selection of entomopathogenic nematodes (Steinernematidae and Heterorhabditidae, Nematoda) for the biological control of cranefly larvae *Tipulapaludosa* (Tipulidae, Diptera). Journal of Plant Diseases and Protection. 100(4):343-353.

Elise N ., Joe S., Diana S ., Nabil N. 2015. *In vitro* susceptibility of the pea leafminer*Liriomyzahuidobrensis* pupae to entomopathogenic*Heterorhabditisindica* and *Beauveriabassiana*. Lebanese Science Journal. 16. 19-26.

Foelkel E, Voss M, Monteiro LB, Nishimura G. 2017. Isolation of entomopathogenic nematodes in an apple orchard in Southern Brazil and its virulence to *Anastrephafraterculus* (Diptera:Tephritidae) larvae, under laboratory conditions. Brazilian Journal of Biology.77(1):22-28.

Garriga A, Morton A, Garcia-del-Pino F. 2018. Is *Drosophila suzukii* as susceptible to entomopathogenic nematodes as *Drosophila melanogaster* ? Journal of Pest Science. 91(2):789-98.

Gava CAT., Paranhos BAJ.2023. Combining the virulent *Beauveriabassiana* (Balsam) Vuillemin LCB289 and nematode strains to control pupae of *Ceratitis capitata* Wiedemann. Biocontrol Sci. Technol., 33: 383-396

Gazit Y., Rossler Y., Glazer I., 2000. Evaluation of entomopathogenic nematodes for the control of Mediterranean fruit fly (Diptera: Tephritidae). Biocontrol Science and Technology. 10: 157-164.

Godjo A., Chabi N., Zadji L., Dossou P., Batcho O., Baimey H., Bonou W., Sinzogan AAC., Bokonon-Ganta A., Decraemer W. 2021.Evaluation of the ability of indigenous nematode isolates of *Heterorhabditistaysearae* and *Steinernemakandii* to control mango fruitfly*Bactrocera dorsalis* under laboratory, semi-field and field conditions in Northern Benin. Crop Prot., 149, 105754

Grewal PS., Koppenhöfer AM., Choo HY. 2005. Lawn, turfgrass and pasture applications. In: Grewal PS., Ehler RU., Shapiro-Ilan DI. (Eds.), Nematodes As Biocontrol Agents. CABI Publishing, Wallingford, pp. 115-146.

Grewal PS., Richardson PN. 1993. Effects of application rates of *Steinernemafeltiae* (Nematoda: Steinernematidae) on control of the mushroom sciarid fly *Lycoriellaauripila*. Biocontrol Science and Technology. 3:29-40.

Hara AH., Kaya HK., Gaugler R., LeBeck LM., Mello CL.1993. Entomopathogenic nematodes for biological control of the leafminer, *Liriomyzatrifolii* (Dipt. Agromyzidae) (Rhabditida: Steinernematidae). Entomaphaga 38:359-369.

Harris MA., Oetting RD., Gardner WA. 1995. Use of entomopathogenic nematodes and a new monitoring technique for control of fungus gnats, *Bradysiacoprophila* (Diptera: Sciaridae), in floriculture. Biol. Control 5(3): 412-418. doi: 10.1006/bcon.1995.1049.

Head, J., Walters, KFA. 2003. Augmentation biological control using the entomopathogenic nematode *Steinernemafeltiae* against the South American leafminer*Liriomyzahuidobrensis*. Conference: USDA-Forest Service, 1st International Symposium on Biological Control of Arthropods, 136-140.10.13140/2.1.2799.5528. DOI:10.13140/2.1.2799.5528.

Heve WK, El-Borai FE, Carrillo D, Duncan LW. 2018. Increasing entomopathogenic nematode biodiversity reduces efficacy against the Caribbean fruit fly *Anastrephasuspensa*:

interaction with the parasitoid *Diachasmimorphalongicaudata*. Journal of Pest Science. 91(2):799-813.

Heve WK., Adjadeh TA., Billahc MK. 2021.Overview and future research needs for development of effective biocontrol strategies for management of *Bactrocera dorsalis*Hendel (Diptera: Tephritidae) in sub-Saharan Africa. Pest Manag. Sci., 77: 4224-4237

Hubner A, Englert C, Herz A. 2017. Effect of entomopathogenic nematodes on different developmental stages of *Drosophila suzukii* in and outside fruits. BioControl 62(5):669-680.

Hussein MA., El-Wakei N, El-Sebai T. 2006. Susceptibility of melon fruit fly, *Dacusciliatus* (Loew) (Diptera: Tephritidae) to Entomopathogenic Nematodes (Rhabditida: Steinernematidae, Heterorhabditidae) and to insecticide. Int. J. Nematol. 16(1): 13-18

Jagdale GB., Casey ML., Canas L., Grewal PS. 2007. Effect of entomopathogenic nematode species, split application and potting medium on the control of the fungus gnat, *Bradysiadifformis* (Diptera:Sciaridae), in the greenhouse at alternating cold and warm temperatures.Biological Control 43:23-30.

Jagdale GB., Casey ML., Grewal PS., Lindquist RK.2004. Application rate and timing, potting medium, and host plant effects on the efficacy of *Steinernemafeltiae* against the fungus gnat, *Bradysiacoprophila*, in floriculture. Biological Control29:296-305.

James, M., Malan, AP., Addison P. 2018. Surveying and screening south African entomopathogenic nematodes for the control of the mediterranean fruit fly, *Ceratitis capitata* (Wiedemann). Crop Protection, 105: 41-48.

Jean-Baptiste MC., Lima de Brida A., Bernardi D., da Costa Días S., Pazini JB., Leite LG., Siciliano-Wilcken SR., Mello-Garcia FR. 2021.Effectiveness of entomopathogenic nematodes against *Ceratitiscapitata* (Diptera: Tephritidae) pupae and nematode compatibility with chemical insecticides. J. Econ. Entomol., 114(1): 248-256.

Jess S., Schweizer H., Kilpatrick M. 2005. Mushroom applications. In: Grewal PS., Ehler RU., Shapiro-Ilan DI. (Eds.), Nematodes As Biocontrol Agents. CABI Publishing, Wallingford, pp. 191-213.

Kamali S., Karimi J., Hosseini M., Campos-Herrera R., Duncan LW. 2013. Biocontrol potential of the entomopathogenic nematodes *Heterorhabditisbacteriophora* and

Steinernemacarpocapsae on cucurbit fly, *Dacus ciliates* (Diptera: Tephritidae). Biocontrol Sci. Tech. 23 (11):1307-1323.

Kapranas A., Anna Chronopoulou A., Peters A., Antonatos S., Lytra I., Milonas P., Papachristos D.2023. Early and off-season biological control of medfly with entomopathogenic nematodes: From laboratory experiments to successful field trials. Biol.Control, 179, 105173

Kapranas A., Chronopoulou A., Lytra IC., Peters A., Milonasa PG., Papachristos DP.2021. Efficacy and residual activity of commercially available entomopathogenic nematode strains for Mediterranean fruit fly control and their ability to infect infested fruits. Pest Manag. Sci. 77: 3964-3969

Karagoz M, Gulcu B, Hazir C, Kaya HK, Hazir S.2009. Biological control potential of Turkish entomopathogenic nematodes against the Mediterranean fruit fly *Ceratitis capitata*.Phytoparasitica 37(2):153-159.

Katumanyane A.2017. Prospects for using EPNs as a bio-control agent against fungus gnats, *Bradysia*spp. in nursery and glasshouse crops. M.Sc. Thesis, Faculty of Agrisciences, Stellenbosch University, South Africa. Stellenbosch University https:// schol ar. sun. ac. za

Kepenekci I., Hazir S., Ozdem A. 2015. Evaluation of native entomopathogenic nematodes for the control of the European cherry fruit fly *Rhagoletiscerasi*L.(Diptera: Tephritidae) larvae in soil. Turk. J. Agric. For. 39(1):74-79.

Koppenhöfer AM. Shapiro-Ilan DI. Hiltpold I.2020. Entomopathogenic nematodes in sustainable food production. Front. Sustain.Food Syst., 4: 125

Koppler K, Peters A, Vogt H. 2003. Initial results in the application of entomopathogenic nematodes against the European cherry fruit fly *Rhagoletiscerasi* L. (Diptera: Tephritidae). IOBC/ WPRS Bullet 23:13-18

Lamba JS, Walia KK, Mrig K, Walia RK.2008. Infectivity and virulence of indigenous entomopathogenic nematodes to mushroom phorid fly, *Megaseliasandhui*. J Biol Control 22(2):411-416

Langford EA., Nielsen UN., Johnson SN., Riegler M., 2013. Susceptibility of Queensland fruit fly, *Bactroceratryoni* (Froggatt) (Diptera: Tephritidae), to entomopathogenic nematodes. Bio Control 96: 34-39.

LeBeck LM., Gaugler R., Kaya HK., Hara AH., Johnson MW. 1993. Host stage suitability of the leafminer*Liriomyzatrifolii* (Diptera: Agromyzidae) to the entomopathogenic nematode *Steinernemacarpocapsae* (Rhabditida: Steinernematidae). Journal of Invertebrate Pathology. 62:58-63.

Lindegren JE., Wong TT., McInnis DO. 1990. Response of Mediterranean fruit fly (Diptera: Tephritidae) to the entomogenous nematode *Steinernemafeltiae* infield tests in Hawaii. Environmental Entomology 19: 383-386

Mahmoud MF. 2007. Combining the botanical insecticides NSK extract, NeemAzal T 5%, Neemix 4.5% and the entomopathogenic nematode *Steinernemafeltiae* Cross N 33 to control the peach fruit fly, *Bactrocerazonata* (Saunders). Plant Prot Sci. 43(1):19-25.

Malan, AP. Manrakhan A. 2009. Susceptibility of the mediterranean fruit fly (*Ceratitis capitata*) and the natal fruit fly (*Ceratitis rosa*) to entomopathogenic nematodes. Journal of Invertebrate Pathology, 100(1): 47-49

Minas RS., Souza RM., Dolinski C., Carvalho RS., Burla RS. 2016. Potential of entomopathogenic nematodes (Rhabditida: Heterorhabditidae) to control Mediterranean fruit fly (Diptera: Tephritidae) soil stages. Nematoda. 3: 1-14.https://doi.org/10.4322/nematoda.02016.

Mokrini F, Laasli SE, Benseddik Y, Joutei AB, Blenzar A, Lakhal H, Sbaghi M, Imren M, Özer G, Paulitz T, Lahlali R, Dababat AA. 2020. Potential of Moroccan entomopathogenic nematodes for the control of the Mediterranean fruit fly *Ceratitiscapitata*Wiedemann (Diptera: Tephritidae). Scientific Reports. 10:19204 https://doi.org/10.1038/s41598-020-76170-7

Mullens BA., Meyer JA., Cyr TL.1987**.** Infectivity of insect-parasitic nematodes (Rhabditida: Steinernematidae, Heterorhabditidae) for larvae of some Manure-breeding flies (Diptera: Muscidae). Environ. Entomol., 16: 769-773.

Navarro MJ., Gea FJ.2014**.** Entomopathogenic nematodes for the control of phorid and sciarid flies in mushroom crops. Pesq.Agropec. Bras.,Brasilia. 49(1): 11-17

Nouh GM, Hussein MA. 2014. The role of entomopathogenic nematodes as biocontrol agents against some tephritid flies. Advances in Biological Research. 8(6):301-306.

Oestergaard J., Belau C., Strauch O., Ester A., van Rozen K., Ehlers RU.2006. Biological control of *Tipulapaludosa* (Diptera: Nematocera) using entomopathogenic nematodes

(*Steinernema* spp.) and *Bacillus thuringiensis*subsp.*israelensis*. Biological Control.39:525-531.

Patterson Stark JE., Lacey LA. 1999. Susceptibility of western cherry fruit fly (Diptera: Tephritidae) to five species of entomopathogenic nematodes in laboratory studies. Journal of Invertebrate Pathology 74(2): 206-208

Pena JM., Carrillo MA., Hallem EA.2015. Variation in the susceptibility of *Drosophila* to different entomopathogenic nematodes. Infect. Immun. 83 (3): 1130-1138.doi: 10.1128/IAI.02740-14

Peters A, Ehlers RU .1994. Susceptibility of leatherjackets (*Tipulapaludosa* and *Tipulaoleracea*; Tipulidae; Nematocera) to the entomopathogenic nematode *Steinernemafeltiae*. JInvertebrPathol 63(2):163-171

Rohde C, Mertz NR, Moino AJ. 2020. Entomopathogenic nematodes on control of mediterranean fruit fly (Diptera: Tephritidae). Rev. Caatinga, Mossoró, 33(4): 974 - 984.

Rohde C., Moino AJ., Mat S., Carvalho FD., Ferreira CS. 2010. Influence of soil temperature and moisture on the infectivity of entomopathogenic nematodes (Rhabditida: Heterorhabditidae, Steinernematidae) against larvae of *Ceratitiscapitata* (Wiedemann) (Diptera: Tephritidae).NeotropEntomol. 39: 608-611.

Scheepmaker JWA., Geels FP., Rutjens AJ., Smits PH., Van Griensven LJ.1998. Comparison of the efficacy of entomopathogenic nematodes for the biological control of the mushroom pests *Lycoriellaauripila* (Sciaridae) and *Megaseliahalterata* (Phoridae). Biocontrol Science and Technology 8:277-287.

Sharifi-Far S., Shapiro-Ilan DI., Brownbridge M., Hallett RH.2018. The combined approach of strain discovery and the inbred line technique for improving control of *Delia radicum* with *Heterorhabditisbacteriophora*. Biol. Control 118:37-43. doi: 10.1016/j.biocontrol.2017.12.004

Shaurub EH. 2023.Review of entomopathogenic fungi and nematodes as biological control agents of tephritid fruit flies: Current status and a future vision. Entomol. Exp. Appl. 171: 17-134

Shaurub EH., Soliman NA., Hashem AG., Abdel-Rahman AM. 2015. Infectivity of four entomopathogenic nematodes in relation to environmental factors and their effects on the biochemistry of the Medfly *Ceratitiscapitata* (Wied.)(Diptera: Tephritidae). NeotropEntomol 44 (6): 610-618.

Sher RB., Parrella MP., Kaya HK. 2000. Biological Control of the Leafminer*Liriomyzatrifolii* (Burgess): Implications for intraguild predation between *Diglyphusbegini* Ashmead and *Steinernemacarpocapsae* (Weiser). Biological Control 17(2):155-163.

Simard L., Belair G., Gosselin ME., Dionne J. 2006. Virulence of entomopathogenic nematodes (Rhabditida: Steinernematidae, Heterorhabditidae) against *Tipulapaludosa* (Diptera: Tipulidae), a turfgrass pest on golf courses. Biocontrol Science and Technology.16:789-801.

Sirjani FO., Lewis EE., Kaya HK.2009. Evaluation of entomopathogenic nematodes against the olive fruit fly, *Bactroceraoleae* (Diptera: Tephritidae). Biological Control .48 :274-280

Soliman NA. 2002. Pathological and biochemical effects of some entomopathogenic nematodes on Mediterranean fruit fly, *Ceratitiscapitata* (Diptera: Tephritidae). Ph. D. Thesis, Dept. Entomol. Fac. Sci., Cairo Univ.

Soliman NA.2007. Pathogenicity of three entomopathogenic nematodes to the peach fruit fly, *Bacterocerazonata* (Saunders) and the Mediterranean fruit fly, *Ceratitiscapitata* (Wiedemann) (Diptera: Tephritidae). Egypt J Biol Pest Cont 17:121-124

Stark JEP, Lacey LA 1999. Susceptibility of Western fruit fly (Diptera: Tephritidae) to five species of entomopathogenic nematodes in laboratory studies. J InvertebrPathol 74:206-208.

Ta-un P., Ehlers R-U., Nimkingrat P.2022**.** Effects of soil texture and moisture on the host searching abilities of *Steinernemasiamkayai* against *Bactroceralatifrons*. Nematology, 24: 559-570

Taylor DB., Szalanski AL., Adams BJ. Peterson RD. 1998. Susceptibility of house fly (Diptera: Muscidae) larvae to entomopathogenic nematodes (Rhabditida: Heterorhabditidae, Steinernematidae) .*Environmental Entomology*, 27(6): 1514-1519.

Toledo J, Morán-Aceves BM, Ibarra JE, Liedo P.2023. Can Entomopathogenic Nematodes and their symbiotic bacteria suppress fruit fly pests? A Review. Microorganisms. 11(7):1682. doi: 10.3390 / microorganisms 11071682

Toledo J., Ibarra JE., Liedo P., Gomez A., Rasgado MA., Williams T. 2005. Infection of *Anastrephaludens* (Loew) (Diptera: Tephritidae) larvae by *Heterorhabditisbacteriophora* under laboratory and field condition. Biocontrol Science and Technology 15:627-634.

Torrini G, Mazza G., Benvenuti C., Roversi PF. 2017. Susceptibility of olive fruitfly, *Bactroceraoleae* (Diptera: Tephritidae) pupae to entomopathogenic nematodes. J. Plant Protect Res. 57: 318-320.

Torrini G., Mazza G., Benvenuti C., Simoncini S., Landi S., Frosinini R., Rocchini A., Roversi PF. 2020.Entomopathogenic nematodes as potential biocontrol agents against *Bactroceraoleae* (Diptera: Tephritidae). Biocontrol Sci. Technol. 30: 909-919

Usman M, Gulzar S, Wakil W, Piñero JC, Leskey TC, Nixon LJ, Hofman CO, Wu S., Shapiro-Ilan D. 2020. Potential of entomopathogenic nematodes against the pupal stage of the apple maggot *Rhagoletispomonella* (Walsh) (Diptera: Tephritidae).Journal of Nematology. 52, e2020-79. DOI: 10.21307/jofnem-2020-079

Usman M., Gulzar S., Wakil W.,Wu S., Piñero JC., Leskey TC., Nixon LJ., Oliveira-Hofman C., Toews MD., Shapiro-Ilan D.2020. Virulence of entomopathogenic fungi to *Rhagoletispomonella* (Diptera: Tephritidae) and interactions with entomopathogenic nematodes. J. Econ. Entomol., 113: 2627-2633.

Usman M., Wakil W., Shapiro-Ilan DI.2021. Entomopathogenic nematodes as biological control agent against *Bactrocerazonata* and *Bactrocera dorsalis* (Diptera: Tephritidae). Biol. Control, 163, 104706. https://doi.org/10.1016/j.biocontrol.2021.104706

Wakil W., Usman M., Piñero JC., Wu S., Toews MD., Shapiro-Ilan DI. 2022.Combined application of entomopathogenic nematodes and fungi against fruit flies, *Bactrocerazonata* and *B. dorsalis* (Diptera: Tephritidae): Laboratory cups to field study. Pest Manag. Sci. 78: 2779-2791.

Williams EC., Macdonald OC. 1995. Critical factors required by the nematode *Steinernemafeltiae* for the control of the leafminers*Liriomyzahuidobrensis*, *Liriomyzabryoniae*and *Chromatomyiasyngenesiae*. Annals of Applied Biology 127: 329-341.

Williams EC., Walters KFA. 2000. Foliar application of the entomopathogenic nematode, *Steinernemafeltiae* against leafminers on vegetables. Biocontrol Science and Technology 10: 61-70

Wu H., Gong Q., Fan K., Sun R., Xu Y., Zhang K.2017. Synergistic effect of entomopathogenic nematodes and thiamethoxam in controlling *Bradysiaodoriphaga*Yang and Zhang (Diptera: Sciaridae). Biol. Control, 111:53-60.

Yagc M., Tugba Akdeniz Fırat TA., Dolunay-Erdogus F., Sahin M.2021. Virulence of four entomopathogenic nematode against different stages of the Mediterranean fruit fly, *Ceratitiscapitata*Wiedemann (Diptera: Tephritidae). Egypt. J. Biol. Pest Control, 31:126

Yee WL., Lacey LA. 2003. Stage-specific mortality of *Rhagoletisindifferens* (Diptera: Tephritidae) exposed to three species of *Steinernema* Nematodes. Biological Control 27:349-356.