

Biological control of fall armyworm, *Spodoptera frugiperda* Smith (Lepidoptera: Noctuidae) in maize using *Metarhabditis rainai* (Nematoda: Rhabditidae) in the field

Joseph Adomako

Council for Scientific and Industrial Research

Kofi Frimpong-Anin

Council for Scientific and Industrial Research

Ernestina Narveh Awarikabey

Council for Scientific and Industrial Research

Bismark Abugri

Council for Scientific and Industrial Research

edward Ofori Attah

Council for Scientific and Industrial Research

Patrick Obeng

Council for Scientific and Industrial Research

Yaw Danso

`ydanso219@gmail.com`

Council for Scientific and Industrial Research

Research Article

Keywords: Entomopathogenic nematodes, biological control activity, biopesticides, *Zea mays*

Posted Date: June 4th, 2026

DOI: <https://doi.org/10.21203/rs.3.rs-9619981/v1>

License:   This work is licensed under a Creative Commons Attribution 4.0 International License.

[Read Full License](#)

Additional Declarations: No competing interests reported.

Abstract

Background Key to the sustainable management of fall armyworm, *Spodoptera frugiperda* Smith (Lepidoptera: Noctuidae) in maize is the incorporation of biocontrol options into integrated pest management programs. Demonstrating entomopathogenic nematode field efficacy would yield ultimate acceptance by farmers. Treatments tested in six replications in the open field were: (T₁) No application control, (T₂) Bypel, (T₃) Cypermethrin and (T₄) *Metarhabditis rainai* entomopathogenic nematodes.

Results *Metarhabditis rainai* was in close performance with Cypermethrin and Bypel on fall armyworm larvae mortality, foliage damage severity and cob damage severity. Cypermethrin was (13%; 14.7%), (85%; 92%), and (4%; 7%) higher over the Bypel, Untreated control, and *M. rainai* in experiments one and two, respectively, in grain yield. *Metarhabditis rainai* performed creditably in reducing fall armyworm damage on maize, resulting in high grain yield.

Conclusion *Metarhabditis rainai* performed creditably against the tested commercial insecticides in the field in managing fall armyworm damage to scale up maize yield. Field demonstrations of *M. rainai* entomopathogenic nematodes to manage fall armyworm damage in maize production is important for their use as candidate biocontrol agents.

Background

Maize (*Zea mays* L.) is predicted to be the crop with the largest production volume globally by the year 2025 (CYMMIT and IITA, 2010). In Africa, maize ranks first in economic importance ahead of wheat and rice. It is penciled to spearhead the attainment of food security and the reduction of poverty among rural folks on the continent (AUC 2006). In Ghana, a greater percentage of maize produced goes into local food consumption. An increase in maize productivity would boost food and nutrition security in Ghana (MoFA 2017; MiDA 2010). This is because the livestock and poultry sub-sectors, which are major sources of protein for the citizenry, rely on the maize value chain (MiDA, 2010). Despite the undisputed importance of maize to the Ghanaian economy, the fall armyworm (FAW), *Spodoptera frugiperda* (J.E. Smith) (Lepidoptera: Noctuidae) outbreak destroyed 34,247 ha of maize farms across the country in 2017/18 farming seasons alone. This translated into about 128 million USD (Fugar 2019; MoFA 2017). The FAW larvae feed on young maize foliage and could record a 45% yield loss if unmanaged (Day et al. 2017). Synthetic insecticides are applied profusely to manage the FAW damage, initially led by the central government in 2018 in Ghana. This has resulted in an upsurge in pesticide usage nationwide. However, the widespread use of synthetic pesticides impacts negatively on man, non-target organisms, and their environment (Herrero-Hernandez et al. 2017). Key to sustainable management of FAW damage in maize is the Integrated Pest Management (IPM) approach (Day et al. 2017). The European Union (EC 2009) particularly encourages and applauds IPM because it keeps probable biotic stresses beneath the economic injury threshold. This is made possible due to sequences of prevention, monitoring, and intervention principles, which reduce as much as possible the application of even approved synthetic pesticides (Aschemann-Witzel and Zielke 2017; EU 2018).

Entomopathogenic nematodes (EPNs) are recognized pathogens of soil-dwelling insects. They are responsible for several biological goods and services and also fit well into IPM programs (Campos-Herrera et al. 2021; Lewis et al. 2015) to manage insect pests. EPNs occur naturally in spotted distribution in agricultural soils where they locate appropriate insect hosts (Stock 2015) and kill them between 48 and 72 hours. Demonstrating EPNs' field efficacy against FAW in maize would provide satisfactory evidence that would lead to ultimate farmer acceptance. The objective of the study was to assess the efficacy of *Metarhabditis rainai* (Carta and Osbrink 2005; Sudhaus 2011; Danso et al. 2024) (Nematoda: Rhabditinae: Rhabditoidea) applied on maize under FAW infestation in the open field.

Methods

Study location and experimental setup

Open field experiments were conducted in the major and minor seasons of the year 2024 at the CSIR - Crops Research Institute (01 ° 28' N 06 ° 41' W), Fumesua - Kumasi, Ghana. Some relevant agro-climatic characteristics of the experimental site in the Ejisu district of the Ashanti region of Ghana have been recorded in Table 1. The experimental fields were manually cleared with hoes and cutlasses. The cleared biomass was removed to reveal the soil surface. Maize (*Zea mays* L.) cv. Abontem was planted at three seeds per hill and thinned to two after seedling emergence. The planting distance was 1 m x 0.5 m between rows and intra rows, respectively. Each plot measured 25 m² with a plot interval space of 3 m, wide enough to avoid treatment contamination from neighbouring plots. There were four roles, two each as test and border rows. The number of hills per row was 10, making a total of 40 hills per plot. Each experiment was set up in RCBD fashion with six replications. Treatments were applied four weeks after seedling emergence (WAE). Treatments applied were: T_1 = Cypermethrin (Pyrethroid contact insecticide) as positive control, T_2 = Bypel (*Pierisrapae granulosis* Virus 10,000 PIB/mg + *Bacillus thuringiensis* 16,000 UI/mg), T_3 = *Metarhabditis rainai* (EPNs), and T_4 = No application as negative control. Fall armyworm natural infestation ($\geq 75\%$ infested plants on each plot) was allowed before the application of the treatments.

Table 1
Agro-climatic characteristics of the experimental site in the Ashanti region of Ghana

Region	District	Agro ecology	Soil type	Average annual air temperature	Rainfall regime	Rainfall information
Ashanti	Ejisu	Forest savannah transition	Ferric Acrisol; Asuansi series; Upper top soil: 5 cm greyish brown sandy loam; Topsoil: dark brown gritty clay loam.	21–31 °C	Bimodal	Major season rainfall: March-mid August. Minor season rainfall: September-November peak: October. Average annual rainfall: 1184 mm.
Source: Adu, Asiamah (1992)						

Soil sampling for indigenous entomopathogenic nematodes

Soil sampling was done in plantation crop farms across five regions of the middle belt of Ghana – Ashanti, Bono East, Bono, Ahafo, and Western North. All the sampling regions experience a bimodal rainfall pattern. Some geophysical characteristics of the sampling locations have been presented in Table 2. For an acre (4000 m²) field, the four corners were determined, and sampling was done diagonally using the traverse soil sampling method. Five soil sub-samples were picked at 20 cm depth and composited, weighing 1000 g using a garden hand trowel. The samples were kept in an insulated cool box to keep them hydrated after the removal of all debris and other foreign materials. Those that seemed very dry were moistened with spray water to ensure the movement of nematodes.

Nematodes’ culturing, multiplication and quantification

Each composite sample was processed in triplicate (3x) (Wiesel et al. 2015). To recover EPNs (*Metarhabditis rainai*) (Danso et al. 2024) from the soil samples, the insect baiting (Tarasco et al., 2020) and modified White trap (Bedding and Akhurst, 1975) methods were applied. Five 4th instar FAW, *Spodoptera frugiperda* (Lepidoptera: Noctuidae) larvae were applied to 250 ml of soil in plastic

containers. Small holes in the cover of the container provided maximum aeration and prevented the FAW larvae from escaping. The container was turned upside-down 3x to ensure the mixing of the soil and insect baits. The set-ups were kept in a dark room ($27 \pm 2^\circ\text{C}$) for the FAW larvae infection as displayed (Fig. 2A).

After 72 hours, the set-ups were checked daily for FAW larvae cadavers. The cadavers were rinsed in distilled water (dH_2O) to remove adhering soil particles and sanitized with 0.1% sodium hypochlorite (NaOCl) to prevent other opportunistic microbes from growing on the cadaver. Five disinfected cadavers were placed on each White trap set-up and kept in a dark room at $27 \pm 2^\circ\text{C}$ for 21 days to obtain infective juveniles (IJs) from the cadavers. The placement of the cadavers was done in such a way that they did not touch each other. The modified White trap is made up of a 14 cm diameter Petri dish and an inverted 8.5 cm diameter one wrapped with a kitchen paper towel as exhibited (Fig. 2B). Distilled water was applied to the bigger Petri dish to get the paper towel wet and to facilitate the transfer and collection of the emerging EPNs. The EPN collection was done every other day until the 14th day when the emergence was thought to have ceased (Bhat et al. 2018; 2019). The nematode suspensions were stored in flat-bottom beakers at 15°C for not more than 7 days (Bhat et al. 2020) after assessment and quantification.

Preparation of treatments and application

The *Metarhabditis rainai* suspension was prepared at 1,028 IJs/mL and topped up with tap water for application using a 2L Tecto hand-held manual pressure sprayer as shown (Fig. 1). The same spraying equipment was used to deliver the other treatments after thorough washing (x3) with water on each application occasion to avoid cross-contamination. Cypermethrin (Supra EC, ETG Inputs Ltd, India) and Bypel were applied at 50 g a.i./L and 2.6 ml a.i./L, respectively. Treatments were applied twice, 2nd and 6th weeks after seedling emergence (WAE) at evening hours (16.00–18.00 h) to create a suitable environmental condition for the nematodes to cause infection. All other recommended cultural practices were followed except the crop protection actions. Each experiment was terminated at 12 WAE.

Data collection and analysis

Experiments one and two data sets were analyzed separately on the number of FAW larvae before and after treatment application, foliar damage severity (scale 0–9), cob damage severity (scale 1–9), and grain yield (t/ha) recorded at harvest time. The number of FAW larvae per plot was counted a day before treatment application and post-application count after 72 h using a non-destructive sampling procedure. The foliar damage rating scale (Prasanna et al., 2018) was used as follows: No visible leaf damage (0); only pinhole foliage damage (1); pinhole and shot hole foliar damage (2); small elongated lesions (5–10 mm) on 1–3 leaves (3); mid-sized lesions (10–30 mm) on 4–7 leaves (4), large elongated lesions (> 30 mm) or small portion eaten on 3–5 leaves (5); elongated lesions (> 30 mm) and large portions eaten on 3–5 leaves (6); elongated lesions (> 30 cm) and 50% leaf eaten (7); elongated lesions (30 cm) and large portion eaten on 70% of leaves (8) and complete defoliation (9). Cobs damage severity (Prasanna et al.

2018) was rated as below: No damage to any ears (1); tip (< 3 cm) damage to 1–3 ears (2), tip damage to 4–7 ears (3); tip damage to 7 and more ears and damage to 1–3 kernels below ear tips on 1 to 3 ears (4); tip damage to 7 and more ears and damage to 1–3 kernels below tips of 4 to 6 ears (5); ear tip damage 7–10 ears and damage to 1–4 kernels below tips of 7 to 10 ears (6); ear tip damage to 7–10 ears and damage to 4–6 kernels destroyed on 7–8 ears (7); ear tip damage to all ears and 4–6 kernels destroyed on 7–8 ears (8) and ear tip damage to all ears and 5 or more kernels destroyed below tips of 9–10 ears (9).

The data were analyzed using MANOVA in GENSTAT (18). Cob and foliar damage scores were used as response variables, and the number of treatments was a fixed factor. The number of FAW larvae and grain yield per plot were also used as response variables. The grain yield values of one treatment over the other in an experiment were converted to percentage (%) for readers' appreciation and presentation as follows;

$$\frac{\text{Treatment (a) yield} - \text{Treatment (b) yield}}{\text{Treatment (a) yield}} \times 100$$

Significant means separation was done using LSD (5%).

Results

The number of FAW larvae pre-application was similar on all plots in the entire study. In both experiments, Cypermethrin recorded the least (1, 2) FAW larvae 72 h post application. This was not significantly ($p = \leq 0.05$) different from those of the Bypel (3, 3) and *Metarhabditis rainai* (3, 3). The untreated plots recorded the greatest FAW larvae (72, 83), which were significantly ($p = \leq 0.05$) different from those of the other treatments (Tables 3 and 4). On a scale of 0–9, the Untreated control recorded the greatest (8.6, 8.1) in foliar damage severity, which was significantly different from those of the other treatments. *Metarhabditis rainai* (2.6, 2.5) performance in foliar damage severity was not significantly different from that of Bypel (2.3, 1.8) and Cypermethrin (1.8, 1.8). Bypel (2.7, 1.3); Cypermethrin (2.3, 1.3) and *Metarhabditis rainai* (2.7, 1.9) were significantly similar in reducing cob damage on a scale of 1–9. Untreated plots (7.8, 8.6) recorded the greatest cobs damage significantly. Cypermethrin (7.8, 9.5 t/ha) recorded the highest grain yield. This was (13%, 15%); (85%, 92%) and (4%, 7%) higher over Bypel, Untreated control, and *Metarhabditis rainai* in experiments one and two, respectively (Tables 3 and 4).

Table 3
Treatments' effect on maize under fall armyworm infestation in experiment one

Treatment	Larvae before application	Larvae after application	Foliar damage severity (0–9)	Cobs damage severity (1–9)	Grain yield t/ha
Bypel	79a	3b	2.3b	2.7b	6.8b
Negative control	76a	72a	8.6a	7.8a	1.2a
Cypermethrin	82a	1b	1.8b	2.3b	7.8b
<i>Metarhabditis rainai</i>	83a	3b	2.6b	2.7b	7.5b
LSD (5%)	7.9	2.2	0.8	0.9	1.1
CV	0.7	3.8	6.8	11.8	3.1

Figures with different letters show significance at $p \leq 0.05$ for various treatments.

Table 4
Treatments' effect on maize under fall armyworm infestation in experiment two

Treatment	Larvae before application	Larvae after application	Foliar damage severity (1–9)	Cobs damage severity (0–9)	Grain yield t/ha
Bypel	85a	3b	1.8b	1.3b	8.1b
Negative control	84a	83a	8.1a	8.6a	0.8a
Cypermethrin	84a	2b	1.8b	1.3b	9.5b
<i>Metarhabditis rainai</i>	89a	3b	2.5b	1.9b	8.8b
LSD (5%)	3.6	3.5	0.7	0.7	1.1
CV	2.1	6.4	11.6	14.9	3.1

Figures with different letters show significance at $p \leq 0.05$ for various treatments

Discussion

So far, EPNs being commercially produced as biocontrol agents of insect pests belong to the Steinernematidae and Heterorhabditidae families. These nematodes live in symbiotic relationships with *Xenorhabdus* and *Photorhabdus* bacteria, respectively (Koppenhofer et al. 2020), to cause infection in

host insects. Apart from these two major groups, nematode species of the Rhabditidae family have also demonstrated great potential for entomopathogenicity (Torres-Barragan et al. 2011; Park et al. 2012; Tabassum et al. 2016). Ye et al. (2018) also demonstrated the ability of nematode species of the genera *Metarhabditis* and *Oscheius* to cause infection in insects. In a similar study, Tabassum et al. (2016) recorded up to 71% natural mortality of FAW larvae by endoparasitic nematodes belonging to the Mermithidae family. Fallet et al. (2024) compared the efficacy of Rwandan indigenous EPNs (*Steinernema carpocapsae*), commercial liquid EPNs, and contact insecticide Cypermethrin to manage FAW infestation in maize. All three treatments reduced foliar damage, but the *Steinernema carpocapsae* decreased FAW larvae presence by 50% and increased fresh cob yield by an additional ton/ha compared to the untreated plots. In another field evaluation study, *Steinernema carpocapsae* and mixed EPNs applied @ 500 IJs per 5 g sand per plant to the whorl of sweet corn significantly curtailed FAW larval population and foliar damage, leading to a significantly high cob yield (Ratnakala et al. 2023). That performance was at par with that of the tested synthetic insecticide (Chlorantraniliprole 18.5 SC) as reflected in our current study, where differences between the *Metarhabditis rainai* and Cypermethrin in FAW damage parameters and grain yield did not record significance. *Heterorhabditis indica* did not reduce FAW larvae population significantly compared to *S. carpocapsae* despite proving effective under laboratory conditions (Ratnakala et al. 2023). In the current study, there was about an 8-fold increase in grain yield recorded for *Metarhabditis rainai* over the untreated plots.

Conclusion

Metarhabditis rainai was in close performance with Cypermethrin and Bypel commercial insecticides on FAW larvae mortality, foliar damage severity, and cobs damage severity. The beneficial nematode has proven to be a promising entomopathogenic nematode candidate for FAW management in maize and needs to be further explored. In the future, other populations of entomopathogenic nematodes should be tested against fall armyworm on maize under similar conditions to enlarge their potential as biocontrol agents and limit the over-reliance on synthetic insecticides. Future research should also optimize application methods and also assess the impacts of such beneficial nematodes on other non-target organisms in the immediate ecosystems.

Declarations

Ethical approval and consent to participate

Not applicable.

Consent for publication

All authors declared that there were no issues relating to the journal policies.

Data and materials availability

All data and information on materials used will be made available upon request.

Competing interests

The authors do not have any competing interests to declare.

Clinical trial number

Not applicable.

Funding

The authors acknowledge financial support provided by the Alliance for a Green Revolution in Africa (AGRA - 2017GH006) and Korean-African Food and Agriculture Cooperation Initiative (KAFACI - KAB20200106) to execute the study.

Author contributions

YD conceptualized the investigation, set-up and managed field experiments and wrote the draft manuscript. JA provided software for data analysis, contributed to the experimental set-ups and proof read the manuscript. KFA administered funds for the study, managed the entomological data and proof read the manuscript. ENA helped greatly in the management of the entomological data and proof read the manuscript. BA sampled soil to extract the entomopathogenic nematodes, harvested FAW larvae from infested maize crops to apply as insect-baits and did identification and quantification of the nematode treatment. EOA helped in soil sampling, extraction and quantification of entomopathogenic nematodes. PO collected the entomological data, helped to manage the experiments and applied treatments. All authors read and approved the final manuscript.

Acknowledgements

The authors acknowledge the agricultural extension agents (AEAs) of the ministry of food and agriculture (MoFA) who led the research team to the various maize farms for soil sampling and harvesting of FAW larvae and also, the farmers who made their maize farms available for sampling to generate the entomopathogenic nematodes.

References

1. Adu SV, Asiamah RD (1992) Soils of the Ayensu-Densu Basin, Central, Eastern and Greater Accra Regions of Ghana. Council for scientific and industrial research (CSIR) – Soil research institute. Mem No. 9. 117p
2. Aschemann-Witzel J, Zielke S (2017) Can't buy me green? A review of consumer perceptions of and behaviour towards the price of organic food. J Consumer Affairs 451:211–251.
<https://doi.org/10.1111/joca.12092>

3. AUC (2006) African Union Commission resolution of the Abuja Food Security Summit. Addis Ababa, Ethiopia
4. Bedding RA, Akhurst RJ (1975) A simple technique for the detection of insect parasitic rhabditid nematodes in soil. *Nematologica*. 21:109–110. <https://doi.org/10.1163/187529275x00419>
5. Bhat AH, Chaubey AK, Půža V (2018) The first report of *Xenorhabdus indica* from *Steinernema pakistanense*: co-phylogenetic study suggests cospeciation between *X. indica* and its steinernematid nematodes. *J Helminthol* 92:1–10
6. Bhat AH, Chaubey AK, Shokoohi E, Mashela PW (2019) Study of *Steinernema hermaphroditum* (Nematoda, Rhabditida) from the West Uttar Pradesh, India. *Acta Parasitol* 64:720–737
7. Bhat AH, Sharma L, Chaubey AK (2020) Characterisation of *Xenorhabdus stockiae*, the associated symbiont of *Steinernema surkhetense* with a note on its geographical distribution and virulence. *Egypt Acad J Biol Sci* 13:105–122
8. Campos-Herrera R, Vicente-Díez I, Blanco-Pérez R, Chelkha M, González-Trujillo MM, Puelles M, Cepulytė-Rakauskienė R, Pou A (2021) Positioning entomopathogenic nematodes for the future viticulture: exploring their use against biotic threats and as bioindicators of soil health. *Turkish J Zool* 45:335–346. <https://doi.org/10.3906/zoo->
9. Carta LK, Osbrink W (2005) *Rhabditis rainai* n. sp. (nematode: Rhabditida) associated with the formosan subterranean termite, *Coptotermes formosanus* (Isoptera: Rhinotermitidae). *Nematology* 7:863–879
10. CYMMIT IITA (2010) Maize-Global alliance for improving food security and the livelihoods of the resource-poor in the developing world. Draft proposal submitted by CYMMIT and IITA to the CGIAR Consortium Board. Elbatan. Mexico. 91pp
11. Danso Y, Adomako J, Prempeh R, Danso AB, Amoabeng WB, Frimpong-Anin K, Abugri B, Mochiah BM (2024) Molecular identification of *Metarhabditis rainai* (Nematoda: Rhabditidae) infecting fall armyworm (Lepidoptera: Noctuidae) on maize in Ghana. *J Entomol nematology* 16(1):1–8
12. Day R, Abrahams P, Bateman M, Beale T, Clotley V, Cock M, Colmenarez Y, Corniani N, Early R, Godwin J, Gomez J, Moreno PG, Murphy ST, Oppong-Mensah B, Phiri N, Pratt C, Silvestri S, Witt A (2017) Fall armyworm: Impacts and implications for Africa. *Outlooks Pest Manage* 28(5):196–201. https://doi.org/10.1564/v28_oct_02
13. EC (2009) Regulation (European Commission) 1107/2009 concerning the placing of plant protection products on the market and repealing Council Directives 79/117/EEC and 91/414/EEC. *Official J Eur Union* 52:1–50
14. EU (2018) Regulation (EU) 2018/848 of The European Parliament and of The Council of 30 May 2018 on organic production and labeling of organic products and repealing Council Regulation (EC) 834/2007. *Official Journal of the European Union*
15. Fallet P, Bazagwira D, Ruzzante L, Ingabire G, Levivier S, Bustos-Segura C, Kajuga J, Toepfer S, Turlings TCJ (2024) Entomopathogenic nematodes as an effective and sustainable alternative to

- control the fall armyworm in Africa. PNAS Nexus 3:122.
<https://doi.org/10.1093/pnasnexus/pgae122>
16. Fugar S (2017) Fighting fall armyworm with early warning systems in Ghana. Esoko. Retrieved February 27, 2020, from <https://esoko.com/fighting-fall-armywormghana/>
 17. Koppenhofer AM, Shapiro-Ilan DI, Hiltbold I (2020) Entomopathogenic nematodes in sustainable food production. Front Sustainable Food Syst 4:125
 18. Lewis EE, Hazir S, Hodson A, Gulcu B (2015) Trophic relationships of entomopathogenic nematodes in agricultural habitats. In: Campos-Herrera R (ed) Nematode pathogenesis of insects and other pests: Ecology and applied technologies for sustainable plant and crop protection. Springer International Publishing, AG Switzerland, pp 139–163. https://doi.org/10.1007/978-3-319-18266-7_5
 19. MiDA (2010) Millenium Development Authority Investment opportunity in Ghana: Maize, rice and soybean productivity document. Accra, Ghana. 170p
 20. MoFA (2017) Ministry of Food and Agriculture. Ghana maize strategy document and investment opportunities for the private sector. Statistics, Research and Information Directorate (SRID), Accra, Ghana
 21. Park HW, Kim YO, Ha JS, Youn SH, Kim HH, Bilgrami AL, Shin CS (2012) Effects of associated bacteria on the pathogenicity and reproduction of the insect parasitic nematode *Rhabditis blumi* (Nematoda: Rhabditida). Can J Microbiol 57(9):750–758
 22. Prasanna BM, Joseph E, Regina H, Virginia M (eds) (2018) Fall armyworm in Africa: a guide for integrated pest management, 1st edn. CIMMYT, Mexico
 23. Ratnakala B, Kalleshwaraswamy CM, Rajkumar M, Sharanabasappa S, Deshmukh H, Mallikarjuna B, Narasimhaiah L (2023) Field evaluation of whorl application of sand mixed entomopathogenic nematodes for the management of invasive fall armyworm, *Spodoptera frugiperda* (J. E. Smith) (Lepidoptera: Noctuidae) in sweet corn. Egypt J Biol Pest Control 33:58.
<https://doi.org/10.1186/s41938-023-00706-y>
 24. Sudhaus W (2011) Phylogenetic systematisation and catalogue of paraphyletic Rhabditidae (Secernentea, Nematoda). J Nematode Morphology Syst 14:113–178
 25. Stock SP Diversity, biology and evolutionary relationships. In: Campos Herrera R. Nematode pathogenesis of insects and other pests: ecology and applied technologies for sustainable plant and crop protection. Springer International Publishing, Switzerland AG (2015) 2015, 3–27.
<https://doi.org/10.1007/978-3-319-18266-71>
 26. Tabassum KA, Shahina F, Nasira K, Erum YI (2016) Description of six new species of *Oscheius Andrassy, 1976* (Nematoda: Rhabditida) from Pakistan with a key and diagnostic compendium to species of the genus. Sarhad J Agric 32(4):109–122
 27. Tarasco E, Kary NE, Fanelli E, Mohammadi D, Xingyue L, Mehrvar A, De Luca F, Troccoli A (2020) Modified bait insect technique in entomopathogens survey from the Arasbaran Biosphere Reserve (Iran). Redia 103:129–132

28. Torres-Barragan A, Suazo A, Buhler WG, Cardoza YJ (2011) Studies on the entomopathogenicity and bacterial associates of the nematode *Oscheius carolinensis*. Biol Control 59(2):123–129
29. Wiesel L, Daniell TJ, King D, Neilson R (2015) Determination of the optimal soil sample size to accurately characterize nematode communities in soil. Soil Biochem 80:89–91.
<https://doi.org/10.1016/j.soilbio.2014.09.026>
30. Ye W, Foye S, MacGuidwin AE, Steffan S (2018) Incidence of *Oscheius onirici* (Nematoda: Rhabditidae), a potentially entomopathogenic nematode from the marshlands of Wisconsin, USA. J Nematology 50(1):9–26

Table 2

Table 2 is available in the Supplementary Files section.

Figures



Figure 1

Manual pressure-spraying equipment used to deliver the entomopathogenic nematodes



Figure 2

(A) Fall armyworm larvae applied to soil for infection by entomopathogenic nematodes; (B) Modified White traps with infected FAW larvae cadavers to extract infective juveniles of entomopathogenic nematodes

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- [Table2.docx](#)