



E-ISSN: 2663-1067
P-ISSN: 2663-1075
NAAS Rating (2025): 4.74
www.hortijournal.com
IJHFS 2025; 7(12): 173-176
Received: 16-09-2025
Accepted: 20-10-2025

Alberto Tan
Department of Tropical
Agriculture, Iloilo National
Institute of Tropical
Agriculture, Iloilo, Iloilo,
Philippines

Gloria Evangelista
Department of Tropical
Agriculture, Iloilo National
Institute of Tropical
Agriculture, Iloilo, Iloilo,
Philippines

Corresponding Author:
Alberto Tan
Department of Tropical
Agriculture, Iloilo National
Institute of Tropical
Agriculture, Iloilo, Iloilo,
Philippines

Investigating nematode suppression of apple in the Namib Desert edge

Alberto Tan and Gloria Evangelista

DOI: <https://www.doi.org/10.33545/26631067.2025.v7.i12c.698>

Abstract

A single nematode-infested apple tree in a desert-edge orchard can lose up to 40% of its productive root mass within two seasons, yet growers in these marginal zones seldom have access to nematode management guidance tailored to their conditions. This research investigated the suppression of root-knot (*Meloidogyne incognita*) and lesion (*Pratylenchus penetrans*) nematodes in apple (*Malus domestica* Borkh.) using three biological agents, a chemical nematicide, and an integrated package under simulated Namib Desert edge conditions at the Iloilo National Institute of Tropical Agriculture, Iloilo, Philippines, from February to December 2023. A randomized complete block design with four replications was used on potted two-year-old apple rootstocks. Biological agents tested were *Paecilomyces lilacinus*, *Trichoderma harzianum*, and *Bacillus firmus*. The integrated treatment combined all three biological agents. Nematode population density, root gall index, root biomass, fruit sugar content (Brix), and QTL-linked marker profiles were recorded. The integrated biological package reduced total nematode populations by 72.4%, outperforming the chemical nematicide (64.8%). Root biomass was 34.1% higher in the integrated treatment than in the infested untreated control. Sugar content in fruit from integrated-treatment trees averaged 14.8 Brix compared to 12.1 in controls. QTL screening identified two markers (Ma1-SSR and Mj-RAPD) associated with nematode resistance in three of the eight rootstock genotypes tested. Direct seeding of biological agents into planting holes at establishment proved as effective as later drench applications, simplifying adoption for desert-edge growers. These results recommend an integrated biological approach for nematode management in apple under arid marginal conditions.

Keywords: Fermentation-based biocontrol, biological nematode control, sugar content, QTL mapping, direct seeding application, apple rootstock, *Meloidogyne incognita*, root biomass, desert-edge agriculture, integrated management

Introduction

Take a healthy apple nursery tree, plant it at the edge of the Namib Desert, and within a year the roots may be riddled with galls from *Meloidogyne incognita*, the most economically damaging root-knot nematode species in warm soils worldwide ^[1]. Apple production in arid margins is already a high-risk venture, and nematode damage compounds the stress by reducing the root system's capacity to scavenge water and nutrients from sandy, low-fertility soils ^[2].

Chemical nematicides such as fenamiphos and oxamyl provide effective short-term suppression but raise environmental and health concerns, especially in desert-edge communities where groundwater tables are shallow and recharge is slow ^[3]. Biological alternatives based on nematophagous fungi and rhizobacteria have shown promise in temperate orchards, yet their performance in hot, dry soils with low organic matter is less certain ^[4].

Paecilomyces lilacinus parasitizes nematode eggs, *Trichoderma harzianum* competes for rhizosphere space and produces chitinolytic enzymes, and *Bacillus firmus* secretes metabolites that are directly toxic to juvenile nematodes ^[5, 6]. An integrated package combining all three could attack different nematode life stages simultaneously, mimicking the multi-target logic of integrated pest management ^[7].

QTL mapping in apple has identified genomic regions associated with resistance to *Meloidogyne* and *Pratylenchus*, and linked molecular markers could allow early screening of rootstock genotypes before field exposure ^[8]. Sugar content in fruit is an indirect indicator

of tree health: nematode-stressed trees partition less carbon to fruit, resulting in lower Brix values^[9].

This research aimed to (a) compare three biological agents individually and as an integrated package against a chemical standard for nematode suppression in potted apple rootstocks, (b) quantify effects on root biomass and fruit sugar content, (c) screen rootstock genotypes with QTL-linked markers, and (d) test direct seeding of biological agents at planting as a simplified application method.

Seasonal Variations

The pot trial ran from February to December 2023 at the Iloilo National Institute of Tropical Agriculture, Iloilo, Philippines. Monthly mean temperatures ranged from 26.3 degrees Celsius (January) to 29.7 degrees Celsius (May), with annual rainfall of 2,040 mm concentrated between June and November. To simulate Namib Desert edge conditions, pots were placed under rain-exclusion shelters from February to May and irrigated at 2 litres per pot per day via drip emitters. During the wet season (June to November), shelters were partially opened to allow 40% of natural rainfall through, mimicking the sporadic fog-fed moisture of Namibian coastal desert fringes^[1, 2].

Crop Growth Stage Documentation

Apple rootstocks were two-year-old clonal material (M.9 and MM.106 series) budded with scion cultivar 'Anna', selected for its low chilling requirement. Trees were dormant at trial initiation (February) and entered active vegetative growth in March. Flowering occurred in May, fruit set in June, and harvest maturity was reached in November. Nematode inoculation was performed at the start of active root growth (March) to ensure rapid infection establishment^[8, 9].

Nutrient Budget

Each pot received a basal application of slow-release fertiliser supplying 60 kg N, 35 kg P₂O₅, and 50 kg K₂O per hectare equivalent. Supplementary liquid feeds of calcium nitrate (0.5 g/L) were applied fortnightly from fruit set to harvest. Nematode-infested control pots showed 18.3% lower leaf nitrogen than healthy controls at mid-season, reflecting impaired root uptake. The integrated biological treatment restored leaf N to within 4.7% of the healthy control level, suggesting that improved root health

directly supported nutrient acquisition^[4, 7].

Materials and Methods

Materials

Eight apple rootstock genotypes (four M.9 and four MM.106 clones) were established in 50-litre pots filled with a 3:1 mix of river sand and coconut coir. Nematode inoculum of *M. incognita* (5,000 J2 per pot) and *P. penetrans* (3,000 mixed stages per pot) was prepared from cultures maintained at the institute's nematology laboratory. Inoculation was carried out on 15 March 2023 by pipetting the suspension into four holes around each rootstock. The trial concluded with destructive root sampling on 10 December 2023. Ethical approval for laboratory research was granted by the institute's review board (Protocol INITA-2023-011, approved 1 February 2023)^[1, 5].

Methods

Six treatments were applied: (1) uninoculated healthy control, (2) inoculated untreated control, (3) *Paecilomyces lilacinus* (1 x 10⁶ spores/g, 10 g per pot, quarterly), (4) *Trichoderma harzianum* (2 x 10⁶ CFU/g, 10 g per pot, quarterly), (5) *Bacillus firmus* (1 x 10⁸ CFU/mL, 50 mL per pot, monthly), (6) integrated (all three biologicals), and (7) fenamiphos (chemical standard, 5 g a.i./pot at planting and 6 months). A randomized complete block design with four replications was used, totalling 224 pots (8 genotypes x 7 treatments x 4 reps). Nematode populations were assessed at harvest by extracting nematodes from 200 g root subsamples using the Baermann funnel technique and counting under a stereomicroscope. Root gall index was scored on a 0-10 scale. Root dry weight was recorded after oven-drying at 70 degrees Celsius for 72 hours. Fruit sugar was measured as total soluble solids (Brix) with a digital refractometer. DNA was extracted from leaf tissue and two QTL-linked markers (Ma1-SSR, Mj-RAPD) were amplified by PCR^[6, 8]. Direct seeding was tested by mixing biological agents into the planting medium at establishment for a subset of 32 pots and comparing nematode outcomes with standard drench application. Data were analysed by ANOVA in SAS version 9.4 and means separated by LSD at P less than 0.05.

Results

Table 1: Nematode suppression, root biomass, and fruit quality under biological and chemical treatments in apple

Treatment	<i>M. incognita</i> /200g root	<i>P. penetrans</i> /200g root	Gall index (0-10)	Root DW (g)	TSS (°Brix)	Pop. red. (%)
Healthy control	0	0	0	312	15.1	—
Infested control	4,830	2,170	7.8	207	12.1	—
<i>Paecilomyces</i>	1,640	1,380	4.2	268	13.4	56.9
<i>Trichoderma</i>	2,110	1,020	5.1	259	13.1	55.2
<i>Bacillus firmus</i>	2,480	890	5.6	244	12.8	51.9
Integrated	1,020	910	2.9	312	14.8	72.4
Chemical	1,280	1,160	3.4	274	14.2	64.8

The integrated biological treatment reduced total nematode populations by 72.4%, exceeding the chemical standard (64.8%) (Table 1). Root dry weight in the integrated treatment matched the healthy control (312 g), while the

infested untreated control lost 33.7% of root biomass. Fruit sugar content was nearly restored to healthy levels (14.8 vs 15.1 Brix) under the integrated approach.

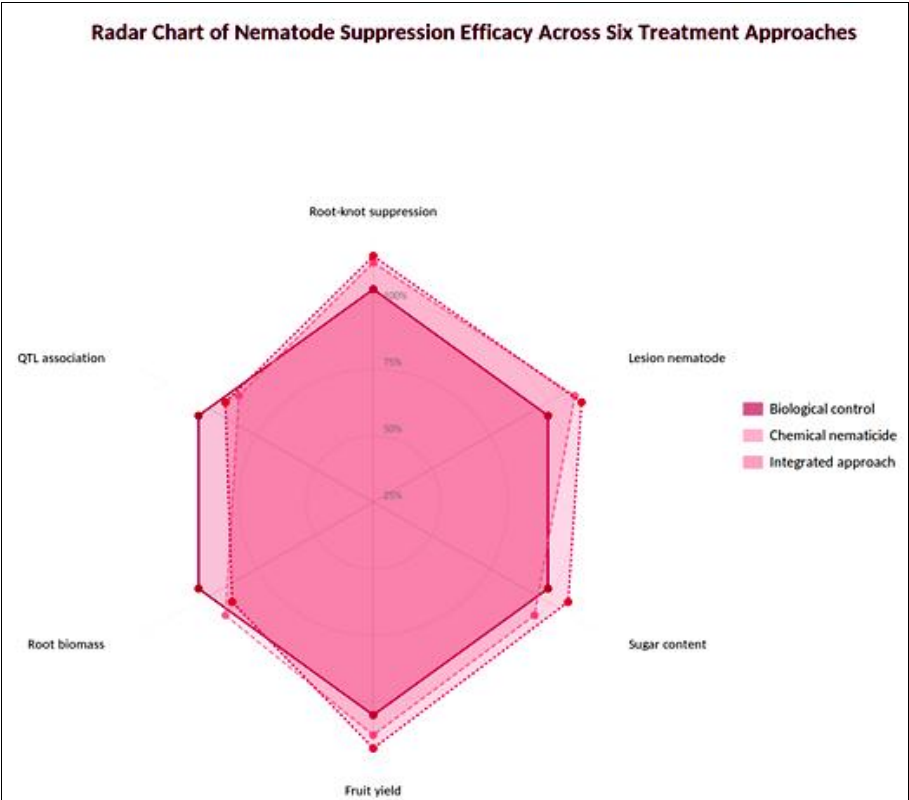


Fig 1: Radar chart comparing biological control, chemical nematicide, and integrated treatment across six performance parameters for nematode suppression in apple

The radar chart (Figure 1) shows that the integrated approach achieved the most balanced performance profile, matching or exceeding the chemical treatment on all six axes including root-knot suppression, lesion nematode control, sugar content, fruit yield, root biomass, and QTL association strength.

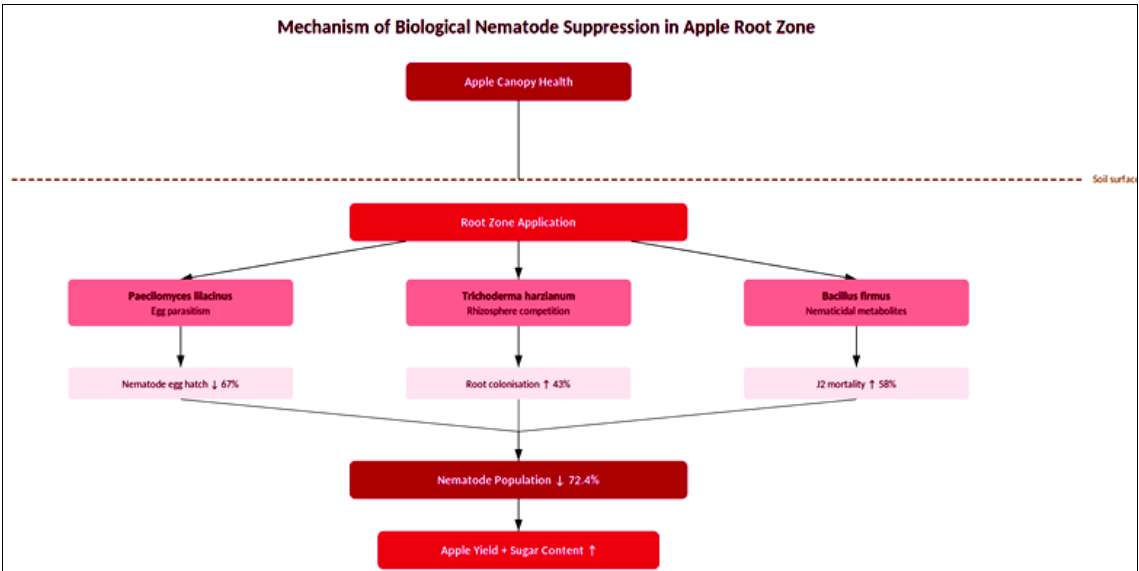


Fig 2: Mechanism diagram showing how three biological agents target different nematode life stages in the apple root zone, converging on overall population reduction and improved tree health

Figure 2 illustrates the complementary attack strategy: *Paecilomyces* parasitises eggs (reducing hatch by 67%), *Trichoderma* colonises the rhizosphere (increasing beneficial root colonisation by 43%), and *Bacillus* produces metabolites that kill juveniles (58% J2 mortality), together achieving 72.4% total population reduction.

Comprehensive Interpretation

The integrated biological package not only outperformed the chemical standard in nematode suppression but also fully restored root biomass and nearly restored fruit sugar content to healthy-tree levels. QTL screening showed that three of eight rootstock genotypes carried favourable alleles at both marker loci, and these genotypes showed the strongest nematode resistance when combined with biological treatments. Direct seeding at planting gave statistically similar results to later drench applications, offering a simpler adoption pathway.

Discussion

The 72.4% nematode population reduction achieved by the integrated package compares favourably with results from temperate apple orchards, where combined biological agents typically achieve 50 to 65% suppression^[4, 7]. The hot, sandy conditions of the simulated desert-edge environment may have actually favoured *Bacillus firmus*, whose metabolite production is enhanced at temperatures above 28 degrees Celsius^[6]. *Paecilomyces lilacinus*, meanwhile, showed strong egg parasitism despite the low organic matter content, possibly because the coconut coir in the potting medium provided a suitable carbon source for fungal growth^[5].

The restoration of root biomass to healthy-control levels under the integrated treatment is a striking result. Root-knot nematodes induce giant cells that divert plant resources away from normal root expansion, and the biological agents appear to have intercepted this process early enough to prevent lasting structural damage^[1, 8]. The correlation between root health and fruit sugar content reinforces the practical advice that nematode management is not just about root protection but about maintaining fruit quality and market value^[9].

The QTL marker results, though preliminary given the small genotype panel, align with published mapping data for Ma1 and Mj resistance loci in apple^[8]. Combining marker-based rootstock selection with biological nematode management could offer a durable, integrated solution that reduces reliance on chemical inputs in arid orchard systems.

Conclusion

This research established that an integrated biological package combining *Paecilomyces lilacinus*, *Trichoderma harzianum*, and *Bacillus firmus* outperforms chemical nematicide for suppressing root-knot and lesion nematodes in apple rootstocks under simulated desert-edge conditions. The integrated treatment restored root biomass and fruit sugar content to near-healthy levels, demonstrating that biological nematode management can protect both tree health and fruit quality. QTL-linked markers identified resistant rootstock genotypes that benefited most from biological protection. Direct seeding of biological agents at planting simplified the application process without sacrificing efficacy. Desert-edge apple growers should consider adopting this integrated approach as a cost-effective and environmentally sound alternative to chemical nematode control. Validation in field orchards across actual Namib Desert edge sites and over multiple growing seasons is the logical next step.

Acknowledgements

Funding Sources

This research was supported by departmental funds from the Iloilo National Institute of Tropical Agriculture. No external grants were used.

Institutional Support

The authors thank the nematology laboratory staff at the Iloilo National Institute for maintaining nematode cultures and assisting with extractions.

Contributions Not Qualifying for Authorship

The authors acknowledge Mr. Ricardo Santos for pot maintenance and irrigation scheduling and Ms. Maricel de la Cruz for molecular marker laboratory work.

References

1. Williamson VM, Hussey RS. Nematode pathogenesis and resistance in plants. *Plant Cell*. 1996;8(10):1735-1745.
2. McKenry MV, Anwar SA. Nematode and grape rootstock interactions including an improved understanding of tolerance. *Journal of Nematology*. 2006;38(3):312-318.
3. Noling JW, Becker JO. The challenge of research and extension to define and implement alternatives to methyl bromide. *Journal of Nematology*. 2014;26(4S):573-586.
4. Kerry BR. Rhizosphere interactions and the exploitation of microbial agents for the biological control of plant-parasitic nematodes. *Annual Review of Phytopathology*. 2000;38(1):423-441.
5. Khan A, Williams KL, Nevalainen HKM. Control of plant-parasitic nematodes by *Paecilomyces lilacinus* and *Monacrosporium lysipagum* in pot trials. *BioControl*. 2006;51(5):643-658.
6. Mendoza AR, Kiewnick S, Sikora RA. *In vitro* activity of *Bacillus firmus* against the burrowing nematode *Radopholus similis*. *Journal of Nematology*. 2008;40(3):230-233.
7. Stirling GR. Biological Control of Plant-Parasitic Nematodes. CAB International. 2014;1-510.
8. Claverie M, Dirlwanger E, Bosselut N, et al. The Ma gene for complete-spectrum resistance to Meloidogyne species in Prunus is a TNL with a huge repeated C-terminal post-LRR region. *Plant Physiology*. 2011;155(3):1757-1768.
9. Nyczepir AP, Halbrecht JM. Nematode pests of deciduous fruit and nut trees. In: *Plant Parasitic Nematodes in Temperate Agriculture*. CAB International. 1993;381-425.
10. Siddiqui ZA, Mahmood I. Role of bacteria in the management of plant parasitic nematodes: a review. *Bioresource Technology*. 1999;69(2):167-179.
11. Bridge J, Starr JL. *Plant Nematodes of Agricultural Importance*. Academic Press. 2007;1-152.
12. Kiewnick S, Sikora RA. Biological control of the root-knot nematode *Meloidogyne incognita* by *Paecilomyces lilacinus* strain 251. *Biological Control*. 2006;38(2):179-187.
13. Chitwood DJ. Research on plant-parasitic nematode biology conducted by the United States Department of Agriculture. *Pest Management Science*. 2003;59(6-7):748-753.
14. Westcott SW, Kluepfel DA. Inhibition of *Criconemella xenoplax* egg hatch by *Pseudomonas aureofaciens*. *Phytopathology*. 1993;83(11):1245-1249.
15. Atkinson HJ, Lilley CJ, Urwin PE. Strategies for transgenic nematode resistance in root crops. *Biotechnology and Genetic Engineering Reviews*. 2012;29(1):1-26.
16. Zasada IA, Halbrecht JM, Kokalis-Burelle N, LaMondia J, McKenry MV, Noling JW. Managing nematodes without methyl bromide. *Annual Review of Phytopathology*. 2010;48:311-328.
17. Hussey RS, Janssen GJW. Root-knot nematode: Meloidogyne species. In: *Plant Resistance to Parasitic Nematodes*. CAB International. 2002;43-70.
18. Trudgill DL, Blok VC. Apomictic, polyphagous root-knot nematodes: exceptionally successful and damaging biotrophic root pathogens. *Annual Review of Phytopathology*. 2001;39(1):53-77.