PLANT SCIENCE TODAY
ISSN 2348-1900 (online)
Vol x(x): xx–xx
https://doi.org/10.14719/pst.4811

HORIZON
e-Publishing Group
HePG

RESEARCH ARTICLE

Response of host Indian Musa germplasm against artificially induced root lesion nematodes (*Pratylenchus coffeae*)

A. Nithya Devi[1], K. Kumanan[2*], P.R. Kamalkumaran[3], R. Arunkumar[4], M. Manikandan[5], S. Sheeba Joyce Roseleen[6] & V.K. Sathya[6]

[1]Dr.MSS Agricultural College and Research Institute, Thanjavur, Tamil Nadu, India

[2]Agricultural College and Research Institute, Pudukkottai, Tamil Nadu, India

[3]Agricultural College and Research Institute, Nagapattinam, Tamil Nadu, India

[4]Coconut Research Station, Veppankulam, Tamil Nadu, India

[5]PAJANCOA & RI, Karaikal, UT of Puducherry, Tamil Nadu, India

[6]Horticultural College and Research Institute for Women, Tiruchirappalli, Tamil Nadu, India

*Email: kumanan@tnau.ac.in

OPEN ACCESS

ARTICLE HISTORY
Received: 25 August 2024
Accepted: 29 September 2024
Available online
Version 1.0 : 27 October 2024

Check for updates

Additional information
Peer review: Publisher thanks Sectional Editor and the other anonymous reviewers for their contribution to the peer review of this work.

Reprints & permissions information is available at https://horizonepublishing.com/journals/index.php/PST/open_access_policy

Publisher's Note: Horizon e-Publishing Group remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

Indexing: Plant Science Today, published by Horizon e-Publishing Group, is covered by Scopus, Web of Science, BIOSIS Previews, Clarivate Analytics, NAAS, UGC Care, etc
See https://horizonepublishing.com/journals/index.php/PST/indexing_abstracting

CITE THIS ARTICLE
Devi AN, Kumanan K, Kamalkumaran PR, Arunkumar R, Manikandan M, Roseleen SSJ, Sathya VK. Response of host Indian Musa germplasm against artificially induced root lesion nematodes (*Pratylenchus coffeae*). Plant Science Today (Early Access). https:/doi.org/10.14719/pst.4811

Abstract

Under greenhouse condition, the host response of fifty-nine banana genotypes (*Musa* spp.) from the Eumusa section to the root-lesion nematode (*Pratylenchus coffeae*) was assessed. In a factorial completely randomized design (FCRD) with five replications, healthy banana suckers of the diploid and triploid accessions were planted in cement pots. Uninoculated controls were included in the experiment as comparison to study the sensitivity of the genotypes. Two varieties (Pisang Lilin and Nendran) with known reaction to lesion nematode were also included as reference clones because of their resistance and susceptibility to *P. coffeae*. Banana accessions maintained in the pots were inoculated with infective juveniles of root-lesion nematode, *P. coffeae* at 45 days after planting at the rate of 400 nematodes/pot. Ninety days after inoculation, the plants were harvested to observe the response of the different banana genotypes to *P. coffeae*. Data were recorded on plant growth (plant height, girth at the base, number of standing leaves, number of roots and weight of the root system), root damage assessment (percentage of infected roots and percentage necrosis) and nematode reproduction. When inoculated with nematodes, the reduction in plant growth attributes was relatively higher in genotypes that were susceptible. The reduction in growth characters *viz*., plants height, number of roots and root fresh weight were maximum in the diploid genotypes Manguthamng (26.80, 27.2, 33.0 %) and Manohar (25.70, 29.2, 35.2 %) and in the triploid genotypes Kaali, Rajthali, Digjowa, Saapkal, Cheenichampa, Dasaman, Borchampa, Jahaji, Manjahaji, Barjahaji and Sabri when inoculated *with Pratylenchus coffeae*. Even after nematode inoculation, root investigations showed that resistant and tolerant genotypes had greater numbers of roots as well as high fresh and dry weight of roots. Root and soil population of nematodes assessed at 90 days after inoculation indicated very high population buildup of *Pratylenchus coffeae* (>28) in diploids Manguthamng and Nendrapadathi and in triploids Jahaji, Manjahaji, Saapkal, Borchampa, Therahaw-1163 and 1164, Ankur-I and Bersain. The rate was the lowest (<9) in the diploid genotypes Kanai Bansi, Kechulepa, *M.balbisiana*, Athiakol, Bhimkol and Aittakola and in the triploids Karthobiumtham and Ankur-II. The results of the experiment showed that the diploids *Musa balbisiana* (BB), Aittakola (BB), Bhimkol (BB), Kechulepa (BB), Kanai Bansi (AA) and Athiakol (BB) and the triploid genotypes Kachkel (ABB), Karthobiumtham (ABB) and Ankur-II (ABB) were resistant to *Pratylenchus coffeae*.

Keywords

artificial inoculation; banana; host response; lesion nematode; pot culture; resistance; tolerance

Introduction

Plantains and bananas (*Musa* spp.) are grown in 130 tropical and subtropical countries and are the fourth most important food crop globally with a production of 135 million tonnes in which India holds a share of 34.53 million tonnes of production (1). Yield of banana in different parts of the world varies greatly with different varieties and production systems. Nematodes also play a considerable role in reducing yields. Nematodes are major economic pests that need to be managed to ensure sustainable fruit production. Nematode parasitism is responsible for 30 - 60 % of the world's productivity losses in bananas (2). It has been observed that 132 different species of nematodes from 54 different taxa are connected to the banana rhizosphere. Of these, 33 genera and 71 species of nematodes have been found in bananas across India (3). The most significant nematodes affecting banana include *Rotylenchulus reniformis, Meloidogyne, Helicotylenchus multicinctus, Pratylenchus goodeyi* and *Pratylenchus coffeae* (4, 5).

There have been reports of 8 different species of the root-lesion nematode infecting *Musa* spp. worldwide. Just 2 of the species, *Pratylenchus coffeae* and *Pratylenchus goodeyi* are known to be harmful pathogens and found to be rather common (4, 6). Root lesion nematodes cause severe black or purple necrosis of cortical and epidermal tissues, which causes lesions and breaking of roots, much like *Radopholus similis* damage (7, 8). The rhizome also contains necrotic lesions (9, 10). Stunting of the plants, an extension of the vegetative cycle, a decrease in leaf size and quantity, a decrease in bunch weight, a reduction in the plantation's productive life and toppling are the results of this damage and loss of the root system (11). The plantains belong to AAB genome in South India, Gujarat, Orissa, Bihar and Assam is known to harbor the root-lesion nematode. Through the infected corm, the nematode is said to have spread to several banana-growing locations, with varying intensities in different soils. In India, the estimated crop loss due to root-lesion nematodes in banana cultivar Nendran was 44.4 % (12). Another species known to exclusively infest Assamese banana plants is *Pratylenchus thornei.*

The cost of nematode management in banana and plantain using nematicides such as aldicarb, phorate and carbofuran is quite prohibitive. Besides, nematicides are very toxic and harm the growers and the environment. Availability of nematode resistant or tolerant *Musa* cultivars could contribute to improve the productivity at a lesser cost with no pollution to environment. Use of resistant lines (landraces or hybrids from breeding programmes) is a promising strategy for controlling nematodes (13). It is consequently necessary to make more concentrated efforts to create *Musa* genotypes that are tolerant or resistant to nematode. Development of resistance against nematodes, therefore, assumes priority in banana breeding programmes in many parts of the world. This study was undertaken to assess the response of 59 banana genotypes from the germplasm collection held at National Research Centre for Banana (NRCB) to the burrowing and lesion nematode under greenhouse condition.

Materials and methods

Table 1 lists the genotypes of 10 diploid, 49 triploid and 2 reference cultivars of *Musa* belonging to the *Eumusa* section, which includes genotypes of wild and farmed bananas kept in the Crop Improvement division's germplasm bank, were tested in pot culture trials for their ability to withstand *Pratylenchus coffeae*. Due of their documented response to *Pratylenchus coffeae*, Pisang Lilin and Nendran were included as reference clones (14). In order to examine the sensitivity of the genotypes, the experiment included controls in which the plants were not inoculated with nematodes.

Preparation of banana plants

Healthy banana suckers of the listed genotypes weighing 750 g were gathered, submerged in water at 55 °C for 15 min, dipped in a 0.1 % Emisan solution (1 g in 1 L of water) for 5 min and then each sucker was treated with 40 g of Carbofuran 3 G granules (the corms are dipped in a slurry solution containing 4 parts clay + 5 parts water and Carbofuran granules are sprinkled to control nematodes). The suckers are utilized as starting material after paring and pralinage treatment (all roots cut off, submerged in mud slurry and dusted with nematicide). They were planted in cement pots that had 20 kg of pot mixture (red soil, sand and farm yard manure in a 2:1:1 ratio) that had been 4 % formaldehyde sterilized. The soil was irrigated with water. The genotype and genomic status names were written on each pot, which were then organized in a factorial completely randomized design (FCRD) with 5 replications.

Culturing of *Pratylenchus coffeae* on carrot disc

Carrots that had been surface sterilized were sliced into discs and put in sterile petri plates. Using a sterile micropipette, nematodes that had been removed from the infected roots using the Baermann-Funnel method were surface sterilized before being placed on the carrot discs. Nematode suspension was applied in tiny drips to the carrot discs' edge. The petri dishes were labeled, parafilm-sealed and kept at 28 °C in an incubator. Periodically, nematodes were subcultured on new carrot discs and the recovered nematodes were employed as an inoculant in pot culture studies (15).

Inoculation of banana plants with nematodes

Infectious juvenile of *Pratylenchus coffeae* nematodes were administered into the pots at a rate of 1000 nematodes per pot containing diploid and triploid banana genotypes. After the roots appeared or 45 days after planting, the nematode suspension was poured into the holes created surrounding the rhizosphere of the plants.

Table 1. Diploid and triploid banana genotypes evaluated in the study.

Diploid genotypes	Genome	Diploid genotypes	Genome
GD_1 – Kanai Bansi	AA	GD_6 - Manohar	BB
GD_2 – Aktoman	AB	GD_7 - *M.balbisiana*	BB
GD_3 – Elakkiebale	AB	GD_8 - Athiakol	BB
GD_4 – Manguthamng	BB	GD_9 - Bhimkol	BB
GD_5 – Kechulepa	BB	GD_{10} - Aittakola	BB
Triploid genotypes	**Genome**	**Triploid genotypes**	**Genome**
GT_1 - Bharat Moni	AAA	GT_{26} - Malai Kali	AAB
GT_2 - Jahaji	AAA	GT_{27} - Kait Long	ABB
GT_3 – Manjahaji	AAA	GT_{28} – Karthobiumtham	ABB
GT_4 – Barjahaji	AAA	GT_{29} - Deshi Kadali	ABB
GT_5 - Honda	AAA	GT_{30} - Agnimalbhog	ABB
GT_6 – Nendrapadathi	AAB	GT_{31} - Kait Khullung	ABB
G_7 – Krishnavazhai	AAB	GT_{32} – Nutepong	ABB
GT_8 – Vannan	AAB	GT_{33} – Kachkel	ABB
GT_9 – Chinali	AAB	GT_{34} - Ankur - II	ABB
GT_{10} – Kaali	AAB	GT_{35} - Kait Shjeng	ABB
GT_{11} – Rajthali	AAB	GT_{36} - Wild Hill	ABB
GT_{12} – Digjowa	AAB	GT_{37} - Longol Local	ABB
GT_{13} – Malbhog	AAB	GT_{38} – Therahaw	ABB
GT_{14} – Saapkal	AAB	GT_{39} – Therahaw	ABB
GT_{15} – Honda	AAB	GT_{40} – Nuzzat	ABB
GT_{16} – Digjowa	AAB	GT_{41} - Veneetu Mannan	ABB
GT_{17} – Jatikal	AAB	GT_{42} - Ankur -I	ABB
GT_{18} – Cheenichampa	AAB	GT_{43} – Garomoina	ABB
GT_{19} – Dasaman	AAB	GT_{44} – Bersain	ABB
GT_{20} – Thiruvananthapuram	AAB	GT_{45} – Gera	ABB
GT_{21} – Borchampa	AAB	GT_{46} – Pordu	ABB
GT_{22} – Krishnasagar	AAB	GT_{47} – Kothia	ABB
GT_{23} – Dudhsagar	AAB	GT_{48} – Chakia	ABB
GT_{24} – Sabri	AAB	GT_{49} – Beula	ABB
GT_{25} – Dinamalakol	AAB		
Reference cultivars			
Pisang Lilin (Resistant)	AA		
Nendran (Susceptible)	AAB		

Data collection

For every genotype 5 replications and for each replication three plants were maintained in the pots. Fifteen plants each in inoculated and uninoculated plants were maintained. Totally 30 plants per genotype was maintained. Ninety days after inoculation, the plants were uprooted to see how various banana genotypes responded to *Pratylenchus coffeae*. To assess the plant growth, root damage induced by nematodes and nematode reproduction, a variety of data were gathered (13). Five 10 cm long portions of roots were examined to determine the percentage of infected roots and the percentage of necrosis. Five viable, 10 cm primary roots were gathered and cut longitudinally. For each root, half of the root cortex was scored to determine the percentage of necrosis. The maximum root necrosis for each of the 5 root halves combined is 100 %, with a maximum of 20 % root necrosis per root half (13). Cobb's sieve and decanting method, together with a modified Baermann funnel technique, were used to determine the nematode population in the soil (16, 17). The roots gathered from the pots were separated into 2 groups: dead roots and functional roots. The root's fresh weight was measured, a 5 g subsample was obtained and nematode extraction was carried out in accordance with INIBAP recommendations (18). At 90 days after inoculation, a root damage evaluation was completed.

All the roots collected from each plant were divided into 2 categories (dead roots and functional roots). The fresh weight of the root was weighed and a sub sample of 5 g was taken and nematode extraction was done as per INIBAP guidelines (18). Root damage assessment was done at 90 DAI.

RLI - Root Lesion Index

For assessing the resistance rating for nematode screening under pot culture studies Root Lesion Index was observed and rated in the roots of the potted plants as given in Table 2 (19).

Table 2. Root Lesion Index.

Sl. No.	Number of lesions	Score
1.	No infection	1
2.	5-10 lesions	2
3.	5-10 lesions with rotting	3
4.	10-15 lesions	4
5.	> 15 lesions with full rotting	5

Corm damage assessment

The corm damage in banana caused by *P. coffeae* was evaluated using the corm lesion index score (Fig. 2) based on the size and number of lesions in the roots as tabulated below in Table 3 (14, 19).

Table 3. Corm Lesion Index.

Sl. No.	Lesion size and number	Score
1.	No lesion	1
2.	One small lesion	2
3.	Several small lesions	3
4.	One large lesion	4
5.	Several large lesions	5

Experimental design and data analysis

Two distinct investigations were carried out for diploid and triploid genotypes with FCRD and 5 replications for each genotype. Using the statistical software AGRES, the recorded data were statistically examined by analysis of variance (ANOVA). Based on the package's results, conclusions were made.

Results and discussion

Significant difference exists between genotypes and among the *Pratylenchus coffeae* inoculated and uninoculated plants with regard to plant biometric characters in diploid and triploid genotypes. In uninoculated plants, the mean average plant biometrical parameters are higher than the plants inoculated with nematodes. The plant height, girth, number of standing leaves, number of roots, fresh root weight, dry root weight recorded in the uninoculated *Musa* genotypes are 55.9 cm, 18.1 cm, 7.3, 47.8, 421.55 g, 59.20 g which was higher than the inoculated genotypes (45.9 cm, 15.3 cm, 5.9, 38.95, 334.35 g, 45.55 g) as shown in the Fig. 1.

In both the experiments involving diploids and triploids, infection with *Pratylenchus coffeae* resulted in a decrease in plant height, girth at the base, number of standing leaves, root number and root weight. But the extent of damage varies among the genotypes with respect to their sensitivity. Significant differences were observed in the percentage of dead roots and percentage of root necrosis of the diploid genotypes (Table 4). The diploid genotypes Kanai Bansi, Kechulepa, *M. balbisiana*, Athiakol, Aittakola and Bhimkol showed significantly less percentage of dead roots and root necrosis comparable to the reference cultivar Pisang Lilin. The final number of nematodes in the roots of the genotypes Manguthamg and Manohar was more than 15 times of the initial inoculum. There were differences in the percentage of dead roots of the triploid genotypes

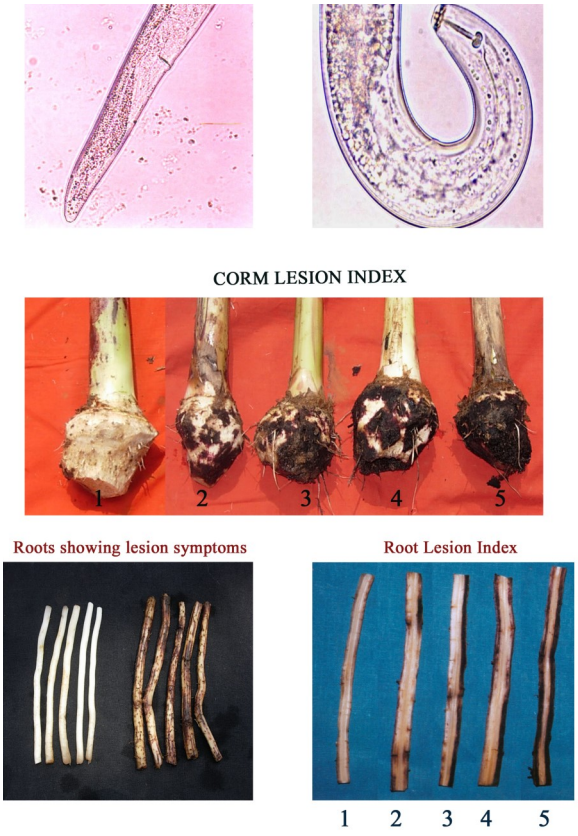

Fig. 2. Root lesion nematode, *Pratylenchus coffeae* and its symptoms.

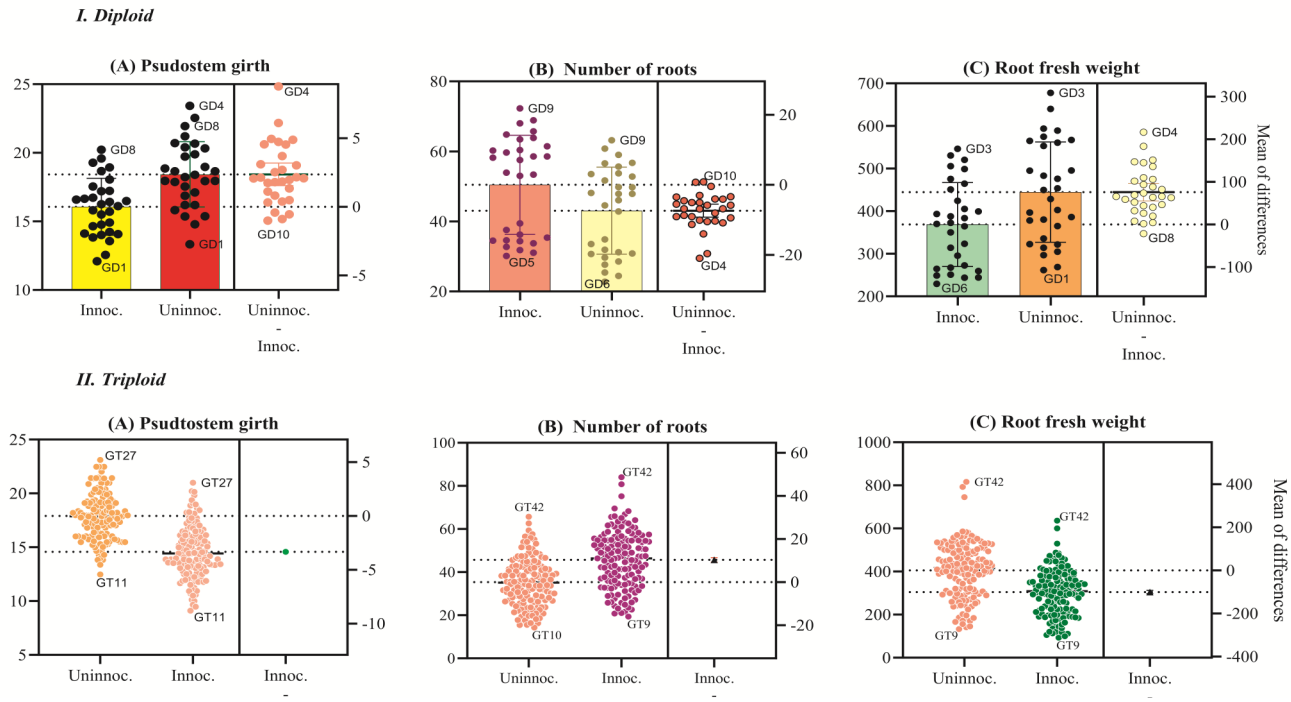

Fig. 1. Effect of *Pratylenchus coffeae* on the growth parameters of diploid and triploid genotypes of banana.

Table 4. Plant growth of 10 diploids and 49 triploid banana genotypes, 90 days after inoculation with *Pratylenchus coffeae* compared with uninoculated control.

	Plant height (cm)	Girth at the base (cm)	Number of standing Leaves	Number of roots	Dry root weight (g)
Diploids					
Uninoculated	60.5	18.4	7.7	50.5	62.50
Inoculated	51.6	16.1	6.4	43.1	50.60
	CD (.05)	**CD (.05)**	**CD (.05)**	**CD (.05)**	**CD (.05)**
G	1.300	0.455	0.188	1.169	1.430
T	0.715	0.220	0.046	0.611	0.738
G x T	2.262	0.698	0.336	1.933	2.333
Triploids					
Uninoculated	51.3	17.8	6.9	45.1	55.9
Inoculated	40.2	14.5	5.4	34.8	40.5
	CD (.05)	**CD (.05)**	**CD (.05)**	**CD (.05)**	**CD (.05)**
G	1.300	0.455	0.188	1.169	1.430
T	0.260	0.091	0.036	0.233	0.286
G x T	1.839	0.644	0.266	1.654	2.022
Mean Avg. (Uninoc.)	55.9	18.1	7.3	47.8	59.2
Mean Avg. (Inoc.)	45.9	15.3	5.9	38.95	45.55
Percentage reduction	17.89	15.47	19.18	18.51	23.06

G - Genotypes; T- Treatments (Inoculated and uninoculated); G x T - Interaction effect.

(Table 5). Ankur II registered the least percentage of infected roots and Jahaji recorded the highest percentage. The triploids Karthobiumtham, Ankur II showed significantly less root necrosis than Jahaji. The final number of nematodes found in the roots was, however, higher than the initial inoculum. In the genotypes Karthobiumtham and Ankur II the final root nematode population was less than 5 times of the initial inoculum.

The rate of population buildup (Table 6) of *Pratylenchus coffeae* in the triploid genotype Karthobiumtham and Ankur-II indicates its resistance to lesion nematode and the genotypes Jatikal, Thiruvananthapuram, Kait Long, Kait Khullung, Deshi Kadali, Agnimalbhog and Kothia were tolerant. The percentage of root necrosis ranged from 10 to 85 %. 10 % of the roots in Karthobiumtham, Athiakol and *Musa balbisiana* showed the least amount of necrosis. There were a minimum number of *Pratylenchus coffeae* nematodes in the roots of Bhimkol (54), Kanai Bansi (58) and Karthobiumtham (65). Even after nematode inoculation, root investigations showed that resistant and tolerant genotypes had greater numbers of roots as well as higher fresh and dry weight of roots. The degree of resistance to nematodes was evaluated using the root necrosis percentage, root lesion index, corm grade and nematode reproduction rate. Diploids Bhimkol (BB), Athiakol (BB), *M. balbisiana* (BB), Aittakola (BB), Kanai Bansi (AA) and Kechulepa (BB) as well as triploids *viz*., Kachkel (ABB), Ankur-II (ABB) and Karthobiumtham (ABB) were found to be resistant to *Pratylenchus coffeae*.

The nomenclature is applied to describe the interactions between the nematode and its host (20). Based on comparisons between genotypes, resistance/ susceptibility and tolerance/sensitivity are defined as independent, relative characteristics of a host plant. Nematode growth and reproduction can be inhibited (resistance) or permitted (susceptibility) by a host plant. It may sustain little harm even from a heavy nematode infection (tolerance) or significant harm even from a very light nematode infection (sensitivity). The impact of nematodes on plant growth was directly related to pot culture evaluation. All genotypes inoculated with *P. coffeae* showed a significant reduction in plant growth metrics, including plant height, plant girth and number of leaves. Though, there was a general reduction in biometrical traits, the genotypes differed in the extent of reduction.

A significant reduction in root weight with *Pratylenchus coffeae* infection was reported (21) whereas in contrary no significant reduction in root weight with infection of the root lesion nematode was noticed (22). It is quite evident that the resistant genotypes had registered the least reduction in almost all the growth parameters indicating their ability to withstand the nematode infection without any perceptible reduction in growth parameters. The reduction in growth parameters in all the susceptible genotypes might be due to invasion of the pathogens into the roots causing damage to the root system, leading to poor uptake of nutrients. This might be due to the nematodes, which feed, multiply and migrate in roots and corm leading to severe destruction of tissues (11). Such root damage might have also resulted in poor nutrient uptake leading to decreased plant growth characters (23).

Measuring the degree of resistance and tolerance of a specific genotype is contingent upon evaluating its capacity to augment or benefit the nematode population. The current study's screening of banana genotypes revealed a range of variations in the amount of nematode tolerance. The genotypes Manguthamng, Kaali, Rajthali, Digjowa, Cheenichampa, Dasaman, Kait Shjeng, Borchampa, Jahaji, Barjahaji, Manjahaji, Longol Local, Therahaw (1163 and 1164), Veneetu Mannan, Nendrapadathi and Sabri exhibited a very high rate of *Pratylenchus coffeae* population build up and more root necrosis. Hence, they are classified as highly susceptible. To identify clones with nematode resistance or tolerance, the root system was examined in terms of the quantity of infected roots, the weight of the infected roots and the severity of lesions in various accessions. Invariably the nematodes reduced the number of roots and root weight in all the accessions screened. The extent of

Table 5. Damage assessment in 10 diploid and 49 triploid banana genotypes and two reference genotypes, 90 DAI with *Pratylenchus coffeae.*

Diploid genotypes	Dead roots (%)	Root Lesion Index	Corm Lesion Index	Root Necrosis (%)					
				1	2	3	4	5	Total
GD_1 - Kanai Bansi	10.53	2	1	10	0	0	5	0	15
GD_2 - Aktoman	23.63	4	3	0	15	10	0	10	35
GD_3 - Elakkiebale	19.57	3	2	10	5	10	0	0	25
GD_4 - Manguthamng	41.67	5	4	5	5	10	15	15	50
GD $_5$ - Kechulepa	10.88	2	1	5	0	5	0	5	15
GD $_6$ - Manohar	45.45	5	4	20	10	5	15	5	55
GD $_7$ - *M.balbisiana*	9.64	2	1	0	0	5	0	5	10
GD_8 - Athiakol	7.55	1	1	0	5	0	5	0	10
GD_9 - Bhimkol	8.97	2	1	0	10	0	0	5	15
GD_{10} - Aittakola	9.77	2	1	0	5	0	5	5	15
SEd	0.458								
CD (0.05)	0.927								
Triploid genotypes	**Dead roots (%)**	**Root Lesion Index**	**Corm Lesion Index**	**Root Necrosis (%)**					
				1	2	3	4	5	Total
GT_1 - Bharat Moni	37.28	4	3	5	5	10	10	5	35
GT_2 - Jahaji	84.88	5	5	15	20	10	20	20	85
GT_3 - Manjahaji	36.51	5	5	20	0	20	15	20	75
GT_4 - Barjahaji	55.47	5	5	20	20	0	20	20	80
GT_5 - Honda	25.64	4	3	5	5	10	10	10	40
GT_6 - Nendrapadathi	44.91	5	4	5	20	15	10	10	60
G_7 - Krishnavazhai	36.61	4	3	10	5	10	0	10	35
GT_8 - Vannan	30.77	4	3	5	10	0	5	10	30
GT_9 - Chinali	30.12	4	3	20	0	5	5	10	40
GT_{10} - Kaali	40.26	5	4	10	5	10	10	10	45
GT_{11} - Rajthali	42.05	5	4	5	5	10	15	15	50
GT_{12} - Digjowa	40.18	5	4	5	15	5	10	10	45
GT_{13} - Malbhog	20.40	3	2	10	5	5	0	5	25
GT_{14} - Saapkal	39.27	5	4	10	0	10	10	15	45
GT_{15} - Honda	28.35	4	3	5	5	10	5	10	35
GT_{16} - Digjowa	25.37	4	3	10	5	0	10	10	35
GT_{17} - Jatikal	24.12	3	3	5	10	5	5	0	25
GT_{18} - Cheenichampa	43.40	5	4	5	10	15	15	20	65
GT_{19} - Dasaman	45.92	4	4	20	5	10	10	0	45
GT_{20} - Thiruvananthapuram	19.43	3	2	5	10	5	5	0	25
GT_{21} - Borchampa	35.71	5	4	10	10	10	15	10	55
GT_{22} - Krishnasagar	25.74	4	3	5	20	5	5	5	40
GT_{23} - Dudhsagar	18.85	3	2	0	10	5	5	5	25
GT_{24} - Sabri	51.54	5	4	10	15	15	10	15	65
GT_{25} - Dinamalakol	32.20	4	3	5	5	10	10	10	40
GT_{26} - Malai Kali	16.85	3	2	10	10	0	5	5	30
GT_{27} - Kait Long	20.59	3	3	5	10	10	5	5	35
GT_{28} - Karthobiumtham	10.68	2	1	0	5	0	0	5	10
GT_{29} - Deshi Kadali	22.57	3	3	10	0	10	10	0	30
GT_{30} - Agnimalbhog	22.52	3	3	10	10	5	0	5	30
GT_{31} - Kait Khullung	22.51	4	3	10	10	10	0	5	35
GT_{32} - Nutepong	21.83	3	2	5	5	5	5	0	20
GT_{33} - Kachkel	18.52	3	2	0	10	0	10	5	25
GT_{34} - Ankur – II	10.26	2	1	5	0	10	0	0	15
GT_{35} - Kait Shjeng	36.18	5	4	10	15	10	15	10	60
GT_{36} - Wild Hill	26.49	4	3	5	10	5	10	10	40
GT_{37} - Longol Local	68.97	5	4	20	10	5	5	20	60
GT_{38} - Therahaw	78.13	5	5	20	0	20	20	20	80
GT_{39} - Therahaw	73.82	5	5	20	15	15	20	10	80
GT_{40} - Nuzzat	12.86	3	2	5	5	0	5	5	20
GT_{41} - Veneetu Mannan	30.39	4	3	5	10	10	5	10	40
GT_{42} - Ankur - I	29.03	4	3	10	10	10	5	5	40
GT_{43} - Garomoina	30.39	4	3	5	5	10	5	10	35
GT_{44} - Bersain	39.78	5	4	10	10	15	15	15	60
GT_{45} - Gera	16.36	3	2	5	0	5	10	5	25
GT_{46} - Pordu	16.96	3	2	10	0	5	5	10	30
GT_{47} - Kothia	12.57	3	3	10	0	10	0	10	30
GT_{48} - Chakia	14.42	3	2	5	10	0	10	0	25
GT_{49} - Beula	14.90	3	2	10	0	5	0	10	25
Reference cultivars									
Pisang Lilin (Resistant)	9.14	1	1	0	5	0	5	0	10
Nendran (Susceptible)	55.86	5	5	10	15	15	10	20	70
SEd	0.731								
CD (0.05)	1.443								

Corm Lesion Index - 1 - No lesion; 2 - One small lesion; 3- Several small lesions; 4 - One large lesion; 5 -Several large lesions

Root Lesion Index -1 - No infection; 2 - 5-10 lesions; 3 - 5-10 lesions with rotting; 4 - 10-15 lesions; 5- >15 lesions with full rotting

Table 6. Nematode reproduction and host response in 10 diploid and 49 triploid banana genotypes and two reference genotypes, 90 DAI with *Pratylenchus coffeae.*

Diploid genotypes	Nematode population				Population build up	Host response
	5 g roots	Entire root system	Total soil	Total population		
GD_1 - Kanai Bansi	58	2982.4	3300	6282.4	6.3	R
GD_2 - Aktoman	115	10276.4	5500	15776.4	15.8	T
GD_3 - Elakkiebale	92	9667.4	4500	14167.4	14.2	MR
GD_4 - Manguthamng	271	19989.0	10700	30689.0	30.7	HS
GD_5 - Kechulepa	65	3407.3	3200	6607.3	6.6	R
GD_6 - Manohar	317	15317.4	8200	23517.4	23.5	HS
GD_7 - *M.balbisiana*	72	4481.3	2700	7181.3	7.2	R
GD_8 - Athiakol	68	5221.0	2800	8021.0	8.0	R
GD_9 - Bhimkol	54	5405.4	2900	8305.4	8.3	R
GD_{10} - Aittakola	70	5455.8	3500	8955.8	9.0	R
SEd	2.964	195.95	**G**	**T**	**GxT**	
CD (0.05)	5.991	396.04	**301.33**	**134.76**	**426.15**	
			151.41	**67.71**	**214.13**	
Triploid genotypes	**Nematode population**					
GT_1 - Bharat Moni	207	15934.9	8500	24434.9	24.4	S
GT_2 - Jahaji	328	20388.5	10900	31288.5	31.3	HS
GT_3 - Manjahaji	310	17360.0	11100	28460.0	28.5	HS
GT_4 - Barjahaji	325	13312.0	11200	24512.0	24.5	HS
GT_5 - Honda	229	13648.4	8900	22548.4	22.5	S
GT_6 - Nendrapadathi	326	21385.6	11400	32785.6	32.8	HS
G_7 - Krishnavazhai	235	8290.8	9000	17290.8	17.3	S
GT_8 - Vannan	240	6369.6	7800	14169.6	14.2	S
GT_9 - Chinali	228	4696.8	7700	12396.8	12.4	S
GT_{10} - Kaali	305	6728.3	10500	17228.3	17.2	HS
GT_{11} - Rajthali	290	7783.6	10200	17983.6	18.0	HS
GT_{12} - Digjowa	302	11361.2	10500	21861.2	21.9	HS
GT_{13} - Malbhog	99	7280.5	4400	11680.5	11.7	MR
GT_{14} - Saapkal	280	21291.2	9700	30991.2	31.0	HS
GT_{15} - Honda	226	9835.5	7600	17435.5	17.4	S
GT_{16} - Digjowa	204	16360.8	7000	23360.8	23.4	S
GT_{17} - Jatikal	185	11984.3	6500	18484.3	18.5	T
GT_{18} - Cheenichampa	280	11709.6	11100	22809.6	22.8	HS
GT_{19} - Dasaman	286	9764.0	11500	21264.0	21.3	HS
GT_{20} - Thiruvananthapuram	162	13682.5	7100	20782.5	20.8	T
GT_{21} - Borchampa	275	19800.0	10600	30400.0	30.4	HS
GT_{22} - Krishnasagar	225	9936.0	8500	18436.0	18.4	S
GT_{23} - Dudhsagar	100	6498.0	5500	11998.0	12.0	MR
GT_{24} - Sabri	296	10703.4	10800	21503.4	21.5	HS
GT_{25} - Dinamalakol	220	13323.2	8000	21323.2	21.3	S
GT_{26} - Malai Kali	96	8605.4	6000	14605.4	14.6	MR
GT_{27} - Kait Long	147	10581.1	7500	18081.1	18.1	T
GT_{28} - Karthobiumtham	65	4927.0	2700	7627.0	7.6	R
GT_{29} - Deshi Kadali	110	9935.2	6800	16735.2	16.7	T
GT_{30} - Agnimalbhog	126	10808.3	7000	17808.3	17.8	T
GT_{31} - Kait Khullung	128	10703.4	7200	17903.4	17.9	T
GT_{32} - Nutepong	102	4306.4	5500	9806.4	9.8	MR
GT_{33} - Kachkel	112	4657.0	5800	10457.0	10.5	MR
GT_{34} - Ankur - II	72	4053.6	3000	7053.6	7.1	R
GT_{35} - Kait Shjeng	305	15445.2	9800	25245.2	25.2	HS
GT_{36} - Wild Hill	220	12746.8	7500	20246.8	20.2	S
GT_{37} - Longol Local	320	14105.6	11100	25205.6	25.2	HS
GT_{38} - Therahaw	328	18696.0	10700	29396.0	29.4	HS
GT_{39} - Therahaw	321	21314.4	11400	32714.4	32.7	HS
GT_{40} - Nuzzat	95	8318.2	5900	14218.2	14.2	MR
GT_{41} - Veneetu Mannan	220	12782.0	8200	20982.0	21.0	S
GT_{42} - Ankur - I	205	24140.8	7600	31740.8	31.7	S
GT_{43} - Garomoina	202	12443.2	8400	20843.2	20.8	S
GT_{44} - Bersain	305	20093.4	10200	30293.4	30.3	HS
GT_{45} - Gera	204	20113.9	8200	28313.9	28.3	MR
GT_{46} - Pordu	100	6520.0	6800	13320.0	13.3	MR
GT_{47} - Kothia	185	13841.7	7800	21641.7	21.6	T
GT_{48} - Chakia	98	8641.6	6000	14641.6	14.6	MR
GT_{49} - Beula	105	8689.8	7000	15689.8	15.7	MR
Reference cultivars						
Pisang Lilin (Resistant)	75	3978	2900	6878.0		R
Nendran (Susceptible)	340	11934	11000	22934.0		HS
			G	T	GxT	
SEd	4.533	264.65	420.44	84.08	594.60	
CD (0.05)	8.940	521.94	213.86	42.77	302.45	

Host Response: R - Resistant; T - Tolerant; MR - Moderately resistant; S - Susceptible; HS - Highly Susceptible

reduction and infection varies with degree of resistance. Compared to the susceptible accessions, the resistant accessions had less root lesions. Among the genotypes screened against *P. coffeae*, the reduction in number of roots was higher in Kaali, Rajthali, Cheenichampa, Dasaman, Kait Shjeng, Borchampa, Jahaji, Manjahaji, Nendrapadathi, Sabri, Bersain and Dinamalakol. Inability of these accessions to produce more roots due to nematode infection can be considered as a susceptible criterion. In turn, the root lesion and corm lesion indices were reduced in resistant genotypes as compared to susceptible genotypes. The resistant genotypes, *M.balbisiana*, Kechulepa, Karthobiumtham, Ankur-II, Kanai Bansi, Athiakol, Aittakola and Bhimkol had a lower population build-up (Fig. 3). Even with the largest nematode population build-up, the triploid genotypes Aktoman, Jatikal, Thiruvananthapuram, Kait Long, Deshi Kadali, Agnimalbhog, Kait Khullung and Kothia displayed the lowest root damage indices. They were therefore classified as tolerant to *Pratylenchus coffeae*.

The reproductive fertility of *Musa* determines the rate of genetic progress (24). In order to use the resistant genotypes in a subsequent breeding effort for nematode resistance, it is necessary to ascertain the levels of male and female fertility of these genotypes. Hence, it will be worthwhile to determine the male and female fertility of the diploid resistant genotypes *viz*., Kanai Bansi, Bhimkol, Athiakol, Aittakola, *M. balbisiana* and the triploid genotype Ankur-II which showed resistance to *P. coffeae* .

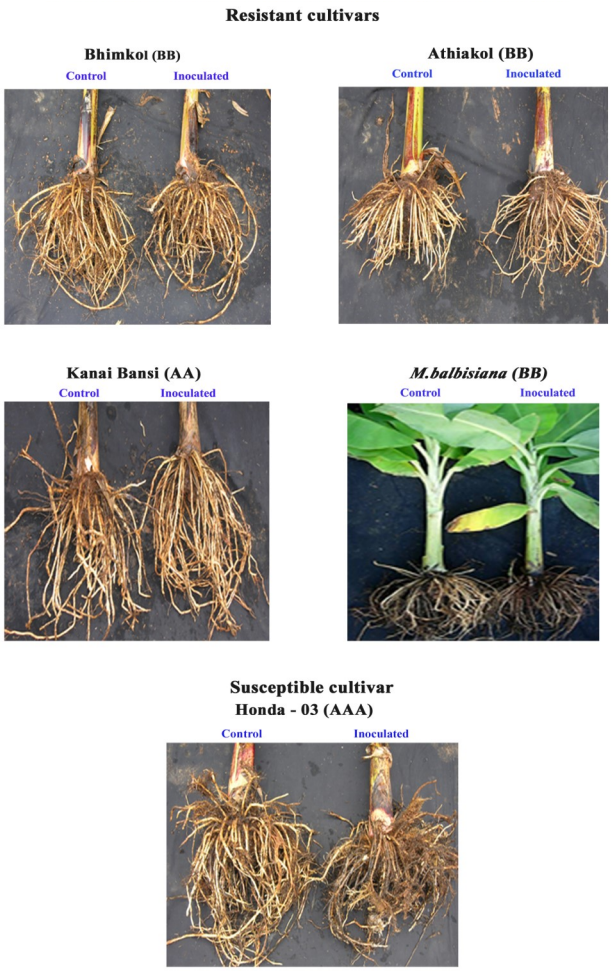

Fig. 3. Screening of *Musa* genotypes against *Pratylenchus coffeae.*

Conclusion

The existence of resistance/tolerance in banana accessions against root-lesion nematode was evident through this present investigation. The results showed that the diploids *Musa balbisiana* (BB), Aittakola (BB), Bhimkol (BB), Kechulepa (BB), Kanai Bansi (AA) and Athiakol (BB) and the triploid genotypes Kachkel (ABB), Karthobiumtham (ABB) and Ankur-II (ABB) were resistant to *Pratylenchus coffeae*. This needs to be reconfirmed through further *in-vitro* and field evaluations, which would be very useful for the horticulturists involved in *Musa* improvement. Prospective genotypes can be used in a follow-up study in the future in a mixed population of nematodes in the field to determine multiple resistances to nematodes before further utilizing the genotypes in a breeding program. The rate of genetic improvement in *Musa* depends on reproductive fertility. Thus, there is a need to determine the levels of male and female fertility of the resistant accessions for their utilization in further breeding programme for nematode resistance. The resistant genotypes identified can be used widely for the effective management of the nematode population. Future research should also focus on genetic modification as a priority in resistance breeding of the banana.

Acknowledgements

This research was funded by the Flemish Association for Development, Co-operation and Technical Assistance, in collaboration with Biodiversity International (previously IPGRI/INIBAP). The authors thank the scientists and technical staff of National research Centre for Banana (NRCB), India for their help with the experimental work.

Authors' contributions

AND has executed the conceptualization, methodology and supervision. AND, KK, PRK and RA conducted the formal analysis and investigation. PRK, RA, MM finalized the preliminary manuscript preparation. KK, MM, VKS and SJR performed the last round of editing and review. The final manuscript was reviewed and approved by all authors.

Compliance with ethical standards

Conflict of interest: Authors do not have any conflict of interests to declare.

Ethical issues: None

References

1. Food and Agriculture Organization of the United Nation. 2022. FAOSTAT.
2. Sikora RA, Coyne D, Quénéhervé P. Nematode parasites of bananas and plantains. In: Sikora RA, Coyne D, Hallmann J and Timper P. (Eds.), Plant-Parasitic Nematodes in Subtropical and Tropical Agriculture (3rd edn.). Wallingford, UK: CAB International; 2018:617-57. https://doi.org/10.1079/9781786391247.0617

3. Sasser JN, Freckman DW. A world perspective of nematology: The role of the society. In: "Vistas on Nematology".Veech JA. and Dickson DW. (ed.). Soc Nematol., Hyattsville, MD. 1987;7-14.
4. Gowen SR, Quénéhervé P, Fogain R. Nematode parasites of bananas and plantains. - In: Luc M, Sikora RA and Bridge J. (Eds.). Plant Parasitic Nematodes in Subtropical and Tropical Agriculture. Wallingford, UK: CAB International; 2005: 611-43. https://doi.org/10.1079/9780851997278.0611
5. Daneel MS, De Waele D. Nematode pests of bananas. In: Fourie H, Spaull WV, Jones R, Daneel MS and De Waele D. (Eds.), Nematology in South Africa: A View from the 21st Century. Cham, Switzerland: Springer; 2017:359-72. https://doi.org/10.1007/978-3-319-44210-5_16
6. Quénéhervé P. Integrated management of banana nematodes. In: Ciancio, A. and Mukerji, K. G. (Eds.), Integrated Management of Fruit Crops and Forest Nematodes. Cham: Springer Science; 2018:3-61. https://doi.org/10.1007/978-1-4020-9858-1_1
7. Blake CD. Root rot of bananas caused by *Radopholus similis* (Cobb) and its control in New South Wales. Nematologica. 1961;6:295-10. https://doi.org/10.1163/187529261X00153
8. Blake CD. The histological changes in banana roots caused by *Radopholus similis* and *Helicotylenchus multicinctus*. Nematologica. 1966;12:129-37. https://doi.org/10.1163/187529266X00121
9. Bridge J, Fogain R, Speijer P. The root lesion nematodes of banana. *Musa* pest fact sheet no. 2. International Network for the Improvement of Banana and Plantain, Montpellier, France; 1997.
10. Pinochet J. Histopathology of the root lesion nematode, *Pratylenchus coffeae* on plantains, Musa AAB. Nematologica. 1978;24(3):337-40. https://doi.org/10.1163/187529278X00344
11. Gowen SR, Queneherve P. Nematode parasites of bananas, plantains and abaca. In: Plant Parasitic Nematodes of Subtropical and Tropical Agriculture. 1990;431-60.
12. Sundararaju P, Padmanaban B, Sathiamoorthy S. Efficacy of certain botanicals against root lesion nematodes, *Pratylenchus coffeae* in banana. Nematologia Mediterrania. 2003;31:201-05.
13. Speijer PR, De Waele D. Screening of *Musa* germplasm for resistance and tolerance to nematodes. INIBAP Technical Guidelines, International Network for the Improvement of Banana and Plantain, Montpellier, France. 1997;4.
14. Ramesh Kumar A, Kumar N, Poornima K, Soorianathasundaram K. Screening of *in vitro* derived mutants of banana against nematodes. African Journal of Biotechnology. 2012;11 (88):15451-56. https://doi.org/10.5897/AJB08.587
15. Carlier J, De Waele D, Escalant JV. Global evaluation of Musa germplasm for resistance to *Fusarium* wilt, *Mycospaerella* leaf spot diseases and nematodes. Performance evaluation (A.Vegine and C.Pig, eds).; INIBAP technical guidelines 7. The International Network for the Improvement of Banana and Plantain, Montpellier, France; 2003.
16. Cobb NA. Estimating the nematode population of soil. U. S. D. A. Agri Tech Circ. 1918;1:1-48.
17. Schindler AF. A simple substitute for a Baermann funnel. Plant Disease Report. 1961;45:747-48.
18. Carlier J, De Waele D, Vincent E. INIBAP technical guidelines on global evaluation of Musa germplasm for resistance to *Fusarium* wilt and *Mycosphaerella* leaf spot diseases and nematodes. Edited by Anne Vezina and Claudine Picq. Publ by INIBAP. 2002.
19. Sundararaju P. Nematode pests of banana and their management. Souvenir. Proceedings of the Conference on Challenges of Banana Production and Utilization in First Century; Trichy, India. 24-25 September 1996; 17-19.
20. Bos L, Parlevliet JE. Concepts and terminology on plant/part relationships towards consensus in plant pathology and crop protection. Annual Review of Phytopathology. 1995;33:69-102. https://doi.org/10.1146/annurev.py.33.090195.000441
21. Van Den Bergh I, Nguyet DTM, Tuyet NT, Nhi HH, De Waele D. Screening of Vietnamese *Musa* germplasm for resistance to root knot and root lesion nematodes in the greenhouse. Australasian Plant Pathology. 2002;31(4):363-71. https://doi.org/10.1071/AP02041
22. Moens T, Araya M, Swennen R, De Waele D. Screening of *Musa* cultivars for resistance to *Helicotyl*enchus *multicinctus*, *Meloidogyne incognita*, *Pratylenchus coffeae* and *Radopholus similis*. Australasian Plant Pathology. 2005;34(3):299-09. https://doi.org/10.1071/AP05037
23. Ssango F, Speijer PR. Influence of nematode damage on sucker growth of East African highland banana (*Musa* AAA). Mus Africa. 1997;11:7-8.
24. Vuylsteke D, Ortiz R, Swennen R. Genetic improvement of plantains at IITA. In: Breeding Banana and Plantain for Resistance to Diseases and Pests. Gamy J, editor. INBAP, Montpellier, France. 1993;267-82.