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RESPONSE OF SELECTED BANANA VARIETIES TO ROOT KNOT NEMATODE *Meloidogyne incognita* (Kofoid and White)

By

Neethu N. S.

(2013-11-150)

THESIS

Submitted in partial fulfilment of the requirement for the degree of

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DECLARATION

I, Neethu N S (2013 11 150) hereby declare that the thesis entitled **"Response of selected banana varieties to root knot nematode *Meloidogyne incognita* (Kofoid and White)"** is a bonafide record of research work done by me during the course of research and the thesis has not been previously formed the basis for the award to me any degree diploma fellowship or other similar title, of any other University or Society

Neethu N S

2013 11-150

Vellanikkara

Date 12/01/2016

CERTIFICATE

Certified that thesis entitled "**Response of selected banana varieties to root knot nematode *Meloidogyne incognita* (Kofoid and White)**" is a bonafide record of research work done independently by **Ms Neethu N S (2013-11-150)** under my guidance and supervision and that it has not previously formed the basis for the award of any degree diploma, associateship or fellowship to her

Vellanikkara

Date 12/01/2016

Dr Susannamma Kurien
Chairperson (Advisory Committee)
Professor
Department of Agrl Entomology

CERTIFICATE

We, the undersigned members of the advisory committee of **Ms Neethu N. S. (2013-11-150)**, a candidate for the degree of **Master of Science in Agriculture**, with major field in **Agricultural Entomology**, agree that the thesis entitled **"Response of selected banana varieties to root knot nematode *Meloidogyne incognita* (Kofoid and White)"** may be submitted by **Neethu N. S. (2013-11-150)**, in partial fulfilment of the requirement for the degree

Dr. Susannamma Kurien
(Chairperson, Advisory Committee)
Professor
Department of Agricultural Entomology
College of Horticulture, Vellanikkara, Thrissur

Dr. Maicykutty P. Mathew
(Member, Advisory Committee)
Professor and Head
Department of Agricultural Entomology
College of Horticulture
Vellanikkara

Mrs. Sreeja P.
(Member, Advisory Committee)
Assistant Professor
AINP on Agricultural Ornithology
Department of Agricultural Entomology
College of Horticulture, Vellanikkara

Dr. Rema Menon
(Member, Advisory Committee)
Professor and Head
Banana Research Station
Kannara, Thrissur

Dr. K. Nandini
(Member, Advisory Committee)
Professor and Head
Department of Plant Physiology
College of Horticulture
Vellanikkara

External Examiner

Dr A SHANTHI, Ph D,
Professor
Department of Nematology
Tamil Nadu Agricultural University
Coimbatore - 641 003

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Neethu N. S.

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Introduction

1. INTRODUCTION

Banana, a dessert fruit for millions, also known as "Apple of Paradise" is botanically *Musa* spp It is one of the major fruit crops of tropics and subtropics forming a staple diet of millions across the globe It is one of the most popular fruits in the world in terms of per capita consumption as well as the most widely traded fruit in the world India leads first world wide in banana production, contributing 19 71 per cent to global production with total production of 19 19 million tonnes from an area of 5 5 lakh ha (Singh, 2008)

Among the different banana growing states of India, though Kerala ranks third in area, the production and productivity is low This is due to polyclonal system of cultivation, mostly under homestead and perennial conditions This provides a favourable environment for pests and diseases to sustain throughout the year affecting the productivity

More than 134 species of nematodes belonging to 54 genera have been associated with the rhizosphere of banana in the world The extent of yield loss depends on the species of nematodes involved The root knot nematodes *Meloidogyne incognita* (Kofoid and White) *M arenaria* (Neal), *M javanica* (Treub) and *M hapla* Chitwood seriously attack banana and plantain together with the other pathogenic nematodes like burowing nematode, *Radopholus similis* (Cobb) Thorn, root lesion nematode *Pratylenchus coffeae* Filipjev, spiral nematode, *Helicotylenchus multicinctus* and *H dihystera* (Cobb) Sher, cyst nematode, *Heterodera oryzicola* Schmidt and reniform nematode, *Rotylenchulus reniformis* Liniford and Oliveria

In Asia, especially in Southeast Asia which is considered to be the centre of origin of *Musa, Meloidogyne* spp are often the most common and abundant nematode species on many native diploid and triploid varieties grown as culinary and dessert bananas

In India, the root knot nematode, *M incognita* is widely distributed in major banana growing regions of the country, whereas *M javanica* is confined mainly to mid hills and plains, where temperature is usually higher

The attack of root knot nematode forms galls or 'root knots' in the primary and secondary roots (Plate 1 and 2) of plants (Williamson and Hussey, 1996) Since the nematode cause damage to the roots, the affected plants experience impaired absorption of water and nutrients and infested banana plants exhibit general decline, stunting, premature defoliation, unthriftiness and bear only small bunches and fruits In addition, openings created in the roots increase the plant susceptibility to harmful bacterial and fungal organisms, creating secondary detrimental effects on the plant The duration of the crop was prolonged to 13 months in *M incognita* infested plants, whereas the plants protected with nematicides produced mature bunches in 12 months period Crop loss caused by nematodes in banana is very high with an average annual yield losses estimated as 20 per cent worldwide (Sasser and Freckman, 1987)

Management of this nematode relies mainly on the repeated use of chemical nematicides which maintain yields 50 per cent greater than in untreated plantations (Seenivasan *et al*, 2013) However, the use of chemical nematicides has adverse effect on environment including residue in fruits, ground water contamination, effect on nontarget organisms and toxicity to applicators This necessitates efforts to find alternative methods of nematode management in banana

One of the most effective and economical ways to control plant parasitic nematodes is exploiting resistant/tolerant cultivars of banana Resistance is an incompatible reaction of plants towards nematode infestation Banana breeding has been limited due to its triploid nature and sterility factors However, limited information is available on the existence of sources of resistance and tolerance to root

Plate 1 Symptoms caused by *Meloidogyne incognita* on primary roots of banana

Plate 2 Symptoms caused by *Meloidogyne incognita* on secondary roots of banana

knot nematode in banana Most of the widely grown banana and plantain cultivars are susceptible to root knot nematodes Pinochet (1988) evaluated 15 banana cultivars and accessions against *M incognita* and found that all of them were susceptible to root knot nematode, although different degrees of susceptibility were detected

In this context, an attempt was made in this study to screen the selected banana varieties against root knot nematode, *Meloidogyne incognita* and to elucidate its biochemical basis of resistance

Review of literature

2. REVIEW OF LITERATURE

The root knot nematode, *Meloidogyne incognita* (Kofoid and White, 1919) is an obligate endoparasite having a wide host range More than 2000 plant species have been reported as host plants of *Meloidogyne* spp (Upadhyay and Dwivedi, 2008) These are considered to be a serious problem on important fruit crops *viz* , banana, papaya and grapes Survey for nematodes associated with banana undertaken at Banana Research Station (BRS), Kannara, under the All India Co-ordinated Fruit Improvement Project, in Palakkad, Thrissur, Ernakulam, Idukki, Aleppy, Kollam and Thiruvanathapuram districts revealed the presence of *M incognita* in addition to other species of nematodes Severe infestation of *M incognita* was observed in banana plants grown along with vegetables (Sheela *et al* , 1990, Sheela, 1995)

From late fifties to late seventies several researchers working in Jamaica, Trinidad and Honduras screened edible banana cultivars of *Musa* AAA and *Musa accuminata* in search of possible source of resistance to these nematodes and observed different degrees of susceptibility rather than resistance (Gowen,1976)

Literature pertaining to the pathogenicity and crop loss due to *Meloidogyne* spp on banana, screening of banana accessions against major plant parasitic nematodes and the biochemical basis of resistance are presented below

2 1 PATHOGENICITY AND CROP LOSS DUE TO *Meloidogyne* spp IN BANANA

Studies on pathogenicity of root knot nematode, *M incognita* in banana cv Poovan in greenhouse condition reported significant reduction in plant growth parameters *viz* , plant height, pseudostem girth, number of leaves, leaf area, root length and weight of plant inoculated with 1000 and 10,000 juveniles/ kg soil The highest gall indices of 4.6 and 5.0 were recorded at 1000 and 10,000 J_2/ kg soil inoculum levels and reduction in nematode multiplication were also reported with increase in inoculum level (Jonathan and Rajendran, 2000a).

Jonathan and Rajendran (2000b) also reported that crop losses due to *M. incognita* in banana var. Poovan was 30.9 per cent. Significant reduction in plant height, pseudostem girth, number of leaves and leaf area was observed due to the root knot nematode infestation. The nematode infestations also deteriorate the edible quality of fruits by reducing the carbohydrates, reducing and non-reducing sugars, total soluble solids and ascorbic acid. The root knot infestation delayed the duration of crop by 42 days.

Meloidogyne incognita was reported to produce multiple galls and severe destruction in ornamental *Musa* species, *Ensete superbum* (Sundararaju *et al.,* 2003).

A survey conducted at different banana growing areas of Ghana reported 50 to 75 per cent root damage by *Meloidogyne* spp. along with *Pratylenchus coffeae, Rotylenchulus reniformis, Radopholus similis* and *Helicotylenchus multicintus* (Osei *et al.,* 2013).

2.2. SCREENING OF BANANA VARIETIES FOR RESISTANCE AGAINST *Meloidogyne* spp.

Screening of banana germplasm in India as well as in other countries revealed that most of the diploid clones of both cultivated and wild were less prone to nematode damage, but they have very low bunch weight (Pinochet, 1988).

Hebsybai *et al.* (1996) reported that equal preference was exhibited by *M. incognita* to the five varieties of banana, namely, Nendran, Palayankodan, Red banana, Robusta and Poovan in a survey conducted with different varieties of banana in Kerala.

Twenty five diploid (AA group) and seven Fe'i banana varieties were screened for resistance by Stoffelen *et al.* (1999) against *M. incognita* at Papua New Guinea. The number of egg laying females per five gram of root samples were significantly low in the varieties like Bagul (254) and Papat Wung (241), Sar (365), Utafan (349) and Skai (290) when compared to the susceptible reference cultivar Grand Naine (735).

den Bergh *et al.* (2002) evaluated 26 Vietnamese banana accessions from the AA, AAA, AAB, ABB, AB genome groups and some wild accessions for resistance and/or tolerance to *Meloidogyne* spp. under greenhouse conditions. All the tested genotypes were found to be at least as susceptible to *Meloidogyne* spp. as the susceptible reference cv. Grand Naine (AAA) and the final nematode population in the roots was at least 97 times higher than the initial inoculum. The intensity of galling was less in the cv. Man (AAB), Tay (ABB), Ngu Thoc (AA) and Yangambi Km5 (AAA).

A study was conducted in pots to evaluate the resistance of four genotypes of banana to root knot nematode, *Meloidogyne* spp. Infection by root knot nematode brought about an increase in root weight in all banana plants tested because of gall formation. Pisang Jari Buaya showed significantly lowest number of *Meloidogyne* spp. in roots, and was the only banana genotype studied to show some degree of resistance to *Meloidogyne* spp. (Guedira *et al.*, 2004).

Moens *et al.* (2005) conducted a screening study on 31 *Musa* cultivars belonging to the AA, AB, AAA, AAB, ABB, AAAA, AAAB, AABB and *Musa balbisiana* (Colla) genomic groups against *M. incognita* and found that none of the varieties were resistant. The lowest number of *M incognita* was supported by Grand Naine (14223/100 g fresh root) and the highest by FHIA-20 (138545/100 g fresh root).

Pot culture experiment was conducted by Sundararaju and Suba (2006) to understand the resistance reaction of banana against *M. incognita* on five varieties of banana *viz.,* Nendran (AAB), Robusta (AAA), Pisang Jari Buaya (AA), Karthobiumtham (ABB) and *Musa balbisiana* (BBB). The results showed that Pisang Jari Buaya, *M. balbisiana* and Karthobiumtham were resistant whereas cvs. Nendran and Robusta were susceptible to *M. incognita.*

Fifty five banana accessions were evaluated for resistance against *M. incognita* and *M. arenaria* by Queneherve *et al.* (2009) and found that none of the accessions possess resistance against *Meloidogyne* spp. All the accessions and genomes were equally the host of *M. incognita* with multiplication rate ranging from 2.7 (Not named) to 28.2 (Pisang Madu). Most of the genomes comprising *Musa balbisiana* showed a higher susceptibility to *M. arenaria* and the multiplication rate ranged between 6.7 to (Pisang Batu) 30.1 (Pisang Klutuk Wulum).

Das *et al.* (2011) studied the reaction of 24 synthetic banana hybrids to *M. incognita* and found that the hybrids H-531 and H-561 with root galling index of zero were resistant against root knot nematode whereas the hybrids *viz.,* H-511, H-534, H-537, H-571, H-572 and H-589 with root galling index of one was tolerant and rest of the hybrids having root galling index between two and four were rated as susceptible and highly susceptible.

The reaction of six *Musa* genotypes *viz.,* FHIA-18, FHIA-23, Pisang Jari Buaya, Gros Michel, Valery and Yangambi Km5 to *M. incognita* was studied by Araya and De-Waele (2011) and reported that the largest populations of *Meloidogyne* spp. was with FHIA-23, Pisang Jari Buaya and Yangambi Km5.

Das *et al.* (2014a) studied the reaction of nineteen new synthetic banana phase II hybrids including one diploid (AB), four triploid (AAB) and fourteen tetraploid (AABB) against *M. incognita* under field as well as pot condition. The hybrid H-531 (AAB) was rated as resistant based on the nematode population (6,917), functional roots (41.25) and gall index (1). Six hybrids *viz.*, H-02-34, H-03-05, H-03-13, H-04-12, H-04-24 and NPH-02-01were rated as tolerant to *M. incognita* and the remaining were found to be susceptible or highly susceptible.

2.3. SCREENING OF BANANA VARIETIES FOR RESISTANCE AGAINST OTHER NEMATODES

Experiments on nematode penetration and rate of multiplication in Poyo (AAA) and Gros Michel (AAA) roots were carried out in France (Mateille, 1992). The study revealed that the invasion of roots by *Helicotylenchus multicinctus* and *Hoplolaimus pararobustus* were a few (about 15 per cent of the inoculum) in both cultivars during the first two weeks, then increased in Gros Michel. The infection by *Radopholus similis* was observed to be less quick in Gros Michel than that of Poyo. The rate of multiplication of the parasite differed between the banana cultivar and the nematode species. Population of *R. similis* increased in Poyo roots but only with the lower inoculum of 1000 nematodes per plant. At higher inocula the plants decayed and the nematode failed to multiply. In Gros Michel roots, all the inocula of *R. similis* failed tó develop. Multiplication of *H. multicinctus* was similar on the roots of both cultivars but *H. pararobustus* increased inocula in the roots of Gros Michel.

Fifty two clones of *Musa* were evaluated for their susceptibility to *R. similis*, *H. pararobustus* and *M incognita* in two field trials. The AAB plantains showed the greatest susceptibility to both *R. similis* and *H. pararobustus* whereas *Musa* AAA and ABB types showed lesser susceptibility to *R. similis*. Greater number of *R. similis* occurred in Laknao (AAB) in trial A and Esang (AAB) in trial B with 32859 and 13359 *R. similis* per 100 g root fresh weight (RFW) respectively. The least susceptible variety in trial A was Yangambi Km5 (AAA) and in trial B was Pisang Kelat (AAB) with 4.0 and 6.0 *R. similis* per 100 g RFW. The maximum number of *H. pararobustus* found in trial A was 297.9 in Grand Naine and in trial B was 3293.0 on Pisang Trimulin. *M. incognita* recorded maximum in AAB plantain French Sombre in trial A (10 000 per 100 g RFW) and Bluggoe Christine in trial B (9330 per 100 g RFW) (Price, 1993).

Several diploid varieties of *M. acuminata* (Calcutta 4 and Pisang Jari Buaya), triploid *M. acuminata* (Yangambi Km5) and diploid *M. balbisiana* (BB CMR) were found to exhibit resistance against *R. similis* (Sarah *et al.*, 1997).

Fogain and Gowen (1998) conducted field and shade house studies to compare the susceptibility of the Yangambi Km5 to that of other triploid *Musa* clones against *R. similis* and *P. goodeyi*. Results of field trials showed that population of *R. similis* recovered from Yangambi Km5 every two months over a two year period were significantly lower than those from the other cultivars. The shade house experiment revealed that different inoculum levels did not have any significant effect on the susceptibility of Yangambi Km5 to *R. similis*. Population levels of *R. similis* recovered six weeks after inoculation of Yangambi Km5 with 1000 and 10000 *R. similis,* did not differ significantly from population recovered with 100 *R. similis*. In contrast, the number of *R. similis* recovered from French Sombre increased significantly with the inoculum level. This indicated that the rate of development of *R. similis* on Yangambi Km5 was slower than that on French Sombre. They also found that Yangambi Km5 was less susceptible to *P. goodeyi* than French Sombre.

Marin *et al.* (1999) conducted a study on aggressiveness (reproductive fitness and root necrosis) and damage potential of *Radopholus* spp. (Central American and Caribbean population) in two susceptible (Grand Naine and Pisang Mas) and one resistant (Pisang Jari Buaya) banana cultivars. Populations from Guapiles, Costa Rica (CR1), had the highest reproductive fitness and root necrosis on susceptible Grand Naine. Populations from Honduras (H1 and H2) and Belize (B) had lower reproductive fitness on susceptible banana than CR1 which was highly aggressive.

Stoffelen *et al.* (1999) screened 32 banana varieties against root lesion nematodes. They confirmed the resistance of 'Rimina' and 'Menei' to *R. similis* and no source of resistance was found against *P. coffeae.*

Fogain (2000) evaluated 30 *Musa* spp. for resistance to *R. similis* and studied mechanisms of resistance with resistant reference cultivar Yangambi Km5 and the susceptible plantain French Sombre. *M. balbisiana* accessions and clones from ibota subgroup were found to be resistant and most of the diploids were found to be susceptible to *R. similis.* The study of the mechanisms of resistance revealed no difference in the penetration rate of *R. similis* between the resistant check Yangambi Km5 and susceptible check French sombre; however the multiplication rate was significantly lower on Yangambi Km5 and it was found to carry the greatest number of cells with phenolic content.

A screen house experiment was conducted using banana suckers of different genotype against *R. similis* and found that the genotypes Gros Michel, TMB2 × 2521S-31 and 47, TMB2 × 1411S-10, TMB × 2094S-1, TMH × 660K-1 and TMB2 × 2569S-2 supported a reproduction ratio that was not significantly different from that on the resistant check Yangambi Km5 (0.02) (Dochez *et al.,* 2000).

Elain (2000) conducted a pot culture experiment to screen banana hybrids to nematodes and found that the hybrids of H6 × Ambalakadali, H 59 × Anaikomban, H 89 × Anaikomban, H 201 × Ambalakadali and H 201 × H110 showed resistance to *R. similis*. The hybrids Nivediyakadali × Pisang Lilin and H 201 × Red were found to be moderately resistant. The population of *R. similis* was more (1247) in the hybrid Nivediyakadali × Pisang Lilin whereas, *M. incognita* population was high in H 66 × Anaikomban (773.70). The hybrids H 59 × Amalakadali, H 89 × Anaikomban and H 65 × Anaikomban were recorded maximum length of root (93.17 cm), weight (60.87 g) and weight of infected corm (174.93 g) respectively when inoculated with *R. similis.* The length of root was more (46.50 cm) in H 201 × Pisang Lilin, weight was more (31.30 g) in H 6 × Ambalakadali and weight of infested corm was more (116.00 g) in Nivediyakadali × Pisang Lilin when inoculated with *M. incognita*.

Stoffelen (2000) evaluated 68 *Eumusa* and *Australimusa* bananas for resistance to *R. similis*, *P. coffeae* and *Meloidogyne* spp. in early vegetative stage and reported two sources of resistance to *R. similis* in the *Australimusa* section (Fe'i bananas). But no source of resistance was found against *P. coffeae* and *Meloidogyne* spp. Studies on the interaction between banana root growth and nematode reproduction revealed that the nematode reproduction depended on the presence of fresh roots and environmental effects influencing both parameters.

A screening study was conducted with 14 *Musa* genotypes (ten resistant or moderately resistant and three susceptible *Musa* genotypes to Fusarium wilt caused by *Fusarium oxysporum* f.sp. *cubense*) against *R. similis* and *P. coffeae*. The Pisang Jari Buaya accessions ITC 0312 and ITC 0690 and Yangambi Km5 were resistant to *R. similis* because the number of nematodes recovered per root system were lower than the inoculum. Pisang Lilin, Bluggoe, Saba, Gros Michel, Williams, GCTCV 215, GCTCV 119, FHIA-01, PA 03.22, PA 03.44 were rated as susceptible to *R. similis* as Grand Naine. None of the 14 genotypes evaluated were resistant to *P. coffeae*, but the highest number of nematodes per root system was recovered from Bluggoe and Saba from batch one and two (Stoffelen *et al.*, 2000).

Musabyimana *et al.* (2000) evaluated 19 *Musa* cultivars (six AAA from East Africa, three exotic AAA, three AA, two AB, three ABB bananas and two AAB plantains) for resistance to banana weevil, *Cosmopolites sordidus* (Germar) and nematode complex including *H. multicinctus*, *Meloidogyne* spp. and *P. goodei*. They found out that the susceptibility to nematode varied between and within plantains and bananas. Njeru (AA), Muraru (AA), Manjano (AB) and Kamaramasenge (AB) recorded lowest nematode population, whereas Ngonia (AAB) and Kivuvu (ABB) had significantly more nematodes than other cultivars. The diploid AA banana Njeru and Muraru had tolerance to both pests.

The resistance/tolerance study of eight banana cultivars (Robusta, Dwarf Cavendish, Nanjanagud Rasabale, Red Banana, Williams, Grand Naine, Nendran, and Yelakkibale) were carried out against *R. similis*. Out of the eight varieties, only Yelakkibale was relatively tolerant with lowest lesion index of 2.1, nematode population of 100.3 individuals per 250 cc soil and 156 per five gram root (Harish and Nanjegowada, 2000).

Elsen *et al.* (2002) confirmed the susceptible status of Grand Naine, Gros Michel and Cachaco and the resistant status of Pisang Jari Buaya and SH-3142 against *R. similis* in vitro.

den Bergh *et al.* (2002) identified Yangambi Km5 (AAA), Tieu Xanh (AAA), Tieu Mien Nam (AA), Gros Michel (AAA), Com Chua (AAB), Com Lua (AA), Man (AAB), Ngu Thoc (AA) and Grand Naine (AAA) as possible sources of resistance/tolerance to *P. coffeae* from twenty six Vietnamese banana accessions and some wild accessions. The final number of nematodes found from the roots of these genotypes was significantly lower than the initial inoculum. Penetration and development studies of *M. incognita* and *P. coffeae* on Nendran and Poovan banana varieties revealed that the time taken for the penetration was 48 h in cv. Nendran and 72 h in cv. Poovan. The multiplication of nematodes was more favoured in cv. Nendran than in Poovan (Sundararaju *et al.*, 2002).

Twenty eight genotypes of *Musa* spp. were evaluated for resistance and tolerance to *R. similis* through comparison with reference genotypes Grand Naine as susceptible and Pisang Jari Buaya and Yangambi Km5 as resistant. Results revealed that Gros Michel and Highgate were susceptible to *R. similis* as Grand Naine and resistance was reported from SH-3142, SH-3362, SH-3648 and SH-3723 (both TC and Corm plants); SH-2095, SH-3624 (Corm plants); Calcutta 4, Prata Enana, and

FHIA-01. Moderate resistance was shown by SH-3624 (TC plants), SH-3437 (Corm plants), Pelipita, FHIA-18 and FHIA-23. The male parent SH-3386 and SH-3640, and the hybrid FHIA-21 showed some degree of resistance and FHIA-03 showed tolerance to *R. similis* (Viaene *et al.*, 2003).

Krishnamoorthi and Kumar (2004) screened 18 synthetic tetraploid banana hybrids and five parental banana clones against *P. coffeae* under field conditions. Sixteen tetraploid banana hybrids showed less root and corm lesion index than the susceptible clones Red banana and Robusta. The lowest nematode population and multiplication rate was recorded in H-02-29 followed by H-02-26, H-02-34 and Pisang Lilin.

Krishnamoorthy *et al.* (2004) evaluated fifteen diploid banana hybrids against *R. similis* and recorded the lowest root lesion index of five, seven and six, and corm index of zero in hybrids like H-02-08, H-02-09 and H-02-10 followed by H-02-14, H-02-15 and Pisang Lilin respectively. The nematode population in soil and root of these hybrids were minimum.

Dochez (2004) developed *R. similis* resistant tetraploid hybrids by crossing susceptible East African highland bananas with the resistant and widely used wild *Musa* diploid Calcutta 4 (male parent). The diploid banana hybrid population was derived by crossing the diploid hybrids TMB2 × 6142-1 (susceptible) and TMB2 × 8075-7 (resistant). The female parent TMB2 × 6142-1 was derived from the cross between the East African highland banana Nyamwihogora (AAA) and the wild banana Long Tàvoy (AA), which were both susceptible to *R. similis*. The male parent TMB2 × 8075-7 was derived from the cross between the bred hybrid SH-3362 (AA) and the wild banana Calcutta 4 (AA) which were both resistant to *R. similis*. Of the 81 hybrids evaluated, 37 hybrids were resistant, 13 hybrids were partially resistant and 31 hybrids were susceptible to *R. similis*. Results indicated that resistance to

R. similis is controlled by two dominant genes, *A* and *B*, both with additive and interactive effects.

A study was conducted in pots to evaluate the resistance of four genotypes of banana to *R. similis*. The inoculation of *R. similis* produced reduction in length and diameter of the pseudo-trunk as well as in root and aerial mass in all genotypes. Significantly least numbers of *R. similis* was obtained from Pisang Berlin and Pisang Jari Buaya and were considered to show some degree of resistance (Guedira *et al.*, 2004).

A study on field screening of 256 *Musa* accessions at harvesting stage was conducted at BRS, Kannara, against major banana nematodes. The studies revealed that the most resistant or tolerant cultivars belonged to the AAB and AB groups. The AAB cultivars Thekkanthulladen, Malbhog, Padathi, Mottapoovan, Charakali, Kalibow, Amrithapani, Nendran and Karibale recorded an average root necrosis between zero and five per cent. The AB cultivars Agniswar and Poomkannan kadali had an average root necrosis between two and three per cent. The AAA cultivars, such as Grand Naine, Sapumal anamalu, Chakkarakeli, Moris and Monsmarie were susceptible, with an average root necrosis between 50 and 75 per cent. But, the AAA cultivars Namkanika, Karivazha and Nakitemp were recorded as more resistant. The ABB cultivars were equally distributed between the resistant, average and susceptible groups. Sambranimonthan, Paloor and Vellapalayankodan were some of the resistant cultivars in this genomic group (Nair *et al.*, 2004).

Field trials were conducted by Krishnamoorthy *et al.* (2005) on the reaction of different diploid bananas and their parental clones to *H. multicinctus*. They found that the banana hybrids H-201, H-02-08 and cultivars Anaikomban, Ambalakadali, Pisang Lilin and Eraichivazhai supported significantly lower number of nematodes and were rated as resistant. Other hybrids *viz.*, H-204, H-211, H-02-11, H-02-12, H-59, H-65 and H-110 were moderately resistant and H-203, H-205, H-208 and H-66 were found to be susceptible to the nematode.

Moens *et al.* (2005) tested the response of 31 *Musa* cultivars belonging to the AA, AB, AAA, AAB, ABB, AAAA, AAAB, AABB and *M. balbisiana* genomic groups against *H. multicinctus*, *P. coffeae* and *R. similis* under greenhouse conditions. They reported that the cultivar Tjau Lagada (AA) supported significantly lower number of *H. multicinctus* than the susceptible reference cultivar Grand Naine (AAA). The lower population of *P. coffeae* was reported from Yangambi Km5 (AAA), Tjau Lagada, Pisang Bungai (AA) and Pisang Mas (AA) than FHIA hybrids and Grand Naine. The cultivars *viz.*, Tjau Lagada, Kunnan (AB), Paka (AA), Pisang Lemak Manis (AA) and Pisang Ceylan (AAB) showed resistance against *R. similis* as that of the reference resistant cultivar Yangambi Km5.

Dochez *et al.* (2006) evaluated 23 accessions including wild bananas and landraces for resistance to *R. similis* using the individual root inoculation method. The accessions Marau, Pora Pora, Kokopo, Pisang Mas, Saba, Gia Hiu, *M. acuminata* sub sp. *burmannica*, *M. acuminata* sub sp. *malaccensis* and Vudu papua with multiplication rate, percentage root necrosis and mean final population density less than 3.8, 24.0 and 189 respectively were rated as resistant to *R. similis*. Four other accessions Pitu, Yalim, *M. balbisiana* and Yanun yefan showed partial resistance, whereas all others rated as susceptible to *R. similis*.

Pot culture study conducted by Devi *et al.* (2007a) to screen 10 diploids and 49 triploids of wild and cultivated banana accessions to *P. coffeae* revealed that the accessions *viz.*, Karthobiumtham, *M. balbisiana*, Kanai Bansi, Bhimkol, Athiakol, Aittakol and Kechulepa were resistant.

Kavitha *et al.* (2008a) studied the reaction of 24 new synthetic hybrids to *P. coffeae* under artificially inoculated pot condition. Two banana hybrids H-04-05 and H-04-06 were found to be resistant and ten hybrids *viz.*, H-04-01, H-04-03, H-

04-04, H-04-07, H-04-09, H-04-11, H-04-16, H-04-19, H-04-21 and H-04-24 were tolerant and the remaining were rated as susceptible.

Queneherve *et al.* (2009) evaluated 55 banana accessions including AA, AAA, BB genome group and some interspecific hybrids (AAB, AB) for resistance against *R. similis* and *P. coffeae*. The accessions *viz.*, Pisang Jari Buaya (AA), Saing Hill (AA), Pisang Sipulu (AA) and Not Named (AA) were found to be resistant to *R. similis* with multiplication rate of 2.8, 1.9, 1.6 and 1.2 and root infestation of 141 ± 95, 64 ± 16, 69 ± 14 and 82 ± 19 respectively. Seventeen diploid accessions were reported to be partially resistant to *R. similis* and all the other accessions showed different level of susceptibility to *P. coffeae*.

Dochez *et al.* (2009) conducted a field experiment to assess host plant response of fifteen polyploidy plantain and banana cultivars (landraces and hybrids) to a mixture of nematodes including *R. similis*, *H. multicinctus*, *H. dihystera* and *Meloidogyne* spp.. The cultivars tested belong to the AAA dessert banana (Yangambi Km5 and Valery), AAB dessert banana (Pisang Ceylan), ABB cooking banana (Bluggoe and Cardaba), AAB plantain (Obino l'Ewai and Mimi Abue) groups, or were polyploid hybrids derived from dessert bananas (FHIA-1, SH-3640 and SH-3436-9), plantains (FHIA-22, TMP × 2796-5 and TMB × 548-9) and cooking bananas (FHIA-3, FHIA-23). Less damage due to nematode infestation exhibited by SH-3640, Yangambi Km5 and FHIA-23 and did not reduce significantly their plant height, but the average yield loss due to nematode infestation was 29 per cent.

Herradura (2009) evaluated the host response of a selection of Papua New Guinean and Southeast Asian banana varieties to the Davao population of *R. similis*. No sources of resistance to *R. similis* was found among the 32 Papua New Guinean banana varieties evaluated. But, five varieties were identified as tolerant to *R. similis viz.*, Pok Pok (AAB), Ambowga (AA), Muga (AA), Manam (AA) and Migea Arizi

(AA). Among the 34 Southeast Asian banana varieties evaluated, three varieties were identified as resistant to *R. similis viz.*, Kluai Pa 26 (AA), K. Nang Nuan (AAB) and Pisang Papan (AAA). Infection with the Davao population of *R. similis* caused higher plant mortality, toppling and lengthening of the vegetative growth cycle compared with uninfected plants. The banana variety Latundan (AAB) had the lowest nematode population density and a low bunch weight reduction compared with the other banana varieties examined which indicates its partial resistance to *R. similis*.

Hartman *et al.* (2010) evaluated 24 *Musa* genotypes inoculated with combination of *R. similis* and *H. multicinctus* in a field trial. The population densities of these nematodes at the harvesting stage varied considerably by genotype with the highest mean densities recovered from the susceptible check Valery (33,653/100 g root fresh weight) for *R. similis* and TMP-9582-4 (33,310/100 g root) for *H. multicinctus*. Lowest *R. similis* densities (356/100 g root) were recovered from Gros Michel followed by Pisang Awak which had lowest *H. multicinctus* densities (1,025/100 g root). Plant growth, yield, root damage and nematode population densities showed a strong negative association between percentage dead roots, percentage root necrosis, *R. similis* and *H. multicinctus* population densities and yield.

Sundararaju (2010) evaluated 72 *Musa* germplasm for resistance/tolerance to *P. coffeae* and found that, eight cultivars *viz.,* Singhlal, Yenagu Bontha, Malai Kali, Manik Champa, Sakkarachayna, Madavazhai, Kartobiumtham and Marabale were resistant, 15 cultivars were moderately resistant, 5 were tolerant and all other varieties were susceptible or highly susceptible to *P. coffeae.*

Araya and De-Waele (2011) evaluated the reaction of six *Musa* genotypes to *R. similis* and *Helicotylenchus* spp. According to them the varieties Yangambi Km5, Pisang Jari Buaya and FHIA-23 supported the lowest number of *R. similis* which correspond to two, one, and one per cent respectively of the Valery population

(350,665) and FHIA-23, Gros Michel and Yangambi Km5 supported high numbers of *Helicotylenchus* spp. ranging from 37,906 to 75,487 nematodes. Pisang Jari Buaya and Valery hosted the lowest *Helicotylenchus* spp. with 8,606 and 7,507 nematodes respectively.

In vitro derived mutants of banana cv. Robusta (Cavendish AAA) and Rasthali (Silk- AAB) were screened against *P. coffeae* and *R. similis* along with respective susceptible checks (Robusta and Rasthali), tolerant check (Anaikomban-AA) and resistant check (Pisang Lilin- AA). Based on the root and corm damage banana mutants were rated as resistant (Ro Im V_4 6-1-1 and Si Im V_4 10-5-3), moderately resistant (Ro Im V_4 6-2-1) and susceptible (Ro Im V_4 6-1-2 and Si Im V_4 6-2-5) (Kumar *et al*, 2012).

Nineteen new synthetic banana phase II hybrids were evaluated against *H. multicinctus* along with Rasthali (AAB, syn. 'Silk') as the susceptible reference cultivar and Pisang Lilin (AA) as the resistant reference cultivar under field as well as artificially inoculated pot conditions. Based on the root and corm damage the hybrid H-531 (Poovan × Pisang Lilin) with root lesion index of five and corm grade of one was found to be resistant and eight hybrids *viz.*, H-02-34, H-03-05, H-03-13, H-03-17, H-04-12, H-04-24, NPH-02-01 and H-510 were found to be tolerant to *H. multicinctus* (Das *et al.*, 2014b).

2.4. BIOCHEMICAL BASIS OF RESISTANCE IN BANANA AGAINST NEMATODES

Localized concentration of phenols stored in discrete bodies within randomly scattered paraenchyma cells were detected in banana roots by Beckman and Mueller (1970).

Mateille (1994) conducted a comparative histopathological investigation in Poyo and Gros Michel cultivars of *M. acuminata* (AAA triploid) which are inoculated with *R. similis, H. multicinctus* or *H. pararobustus*. Results showed that *R. similis* infected all the cortical parenchyma layers of the roots, reaching the vascular cylinder, but it stayed more superficial in Gros Michel roots. Red-brown cytoplasmic globules appeared in the cortical parenchyma cells of Gros Michel only. *H. multicinctus* infected much of the outer cortical parenchyma in roots of both cultivars with a few phenolic cells occurring around the superficial lesions. *H. pararobustus* penetrated only the immediate sub-epidermal tissues in both cultivars. The differences observed between nematodes and cultivars reflect specific host-nematode interactions on bananas.

Studies on the sources of resistance to *R. similis* in *Musa* and the resistance mechanisms involved revealed relatively greater numbers of preformed phenolic cells in roots of the resistant and intermediately resistant cultivars Yangambi Km5 and Gros Michel than others. But fewer phenolic cells and high numbers of cells with lignified walls were found in another resistant cultivar, Pisang Jari Buaya suggesting a different mechanism of resistance (Fogain and Gowen, 1996.)

Collingborn *et al.* (2001) found that, *Musa* cultivars Dwarf Cavendish, Yangambi Km5 and Kunnan, exhibit considerable differences in resistance to *R. similis* infection. The highly resistant cultivar Kunnan had the highest levels of condensed tannins before and after infection. Tannins had mostly procyanidin character but Kunnan also contained propelargonidins; expected to compounds be involved in the resistance mechanism.

An increased total phenol, orthohydroxy phenol, polyphenol oxidase and peroxidase activities were reported in susceptible hybrids Nivediyakadali × Pisang Lilin to *R. similis* whereas, the lignin content and dry matter content of roots were recorded to be more in resistant hybrids *viz.*, H6 × Ambalakadali, H 59 × Anaikomban, H 89 × Anaikomban, H 201 × Ambalakadali and H 201 × H 110 (Elain, 2000).

Krishnamoorthy *et al.* (2004) conducted a field study on the reaction of fifteen diploid banana hybrids against *R. similis* and reported that H-02-10 and Pisang Lilin recorded higher amount of total phenol content with 711.38 and 1622.10 µg/g respectively, ortho-dihydric phenol (34.10 and 133.60 µg/g respectively) and polyphenol activity (971.51 units/min/g fresh weight) in roots. The nematode population and root and corm lesion index were minimum in these cultivars.

Chlorogenic acid, bound phenol and phenylalanine ammonia lyase were analysed to determine the resistance reaction in eighteen new synthetic tetraploid banana hybrids and five parental clones against *P. coffeae*. The hybrids with less root and corm lesion index *viz.*, H-02-18, H-02-17 and H-02-25 recorded higher content of chlorogenic acid, H-02-30 and H-02-18 recorded higher content of bound phenol and phenylalanine ammonia lyase (Krishnamoorthi and Kumar, 2004).

A study was conducted to evaluate the varietal reaction of four Philippines banana cultivars that had displayed some resistance *in vivo* against an Ugandan population of *R. similis* (Orajay *et al.*, 2004). The cultivars 'Senorita' and 'Pamoti on' displayed the highest levels of resistance while the number of nematodes on 'Matavia' and 'Pisang Lemak Manis' were not significantly different from those on Grand Naine. Staining root sections with Toluidine Blue O revealed the presence of lignified/suberized cell walls in the central cylinder and endodermis of Pisang Jari Buaya and to a lesser extent in Yangambi Km5. Such thickenings were not observed on Grand Naine. Occurrence of phenolic cells in the stele and cortex were observed in the three cultivars but the expected accumulation of such cells in Yangambi Km5 was not detected.

Krishnamoorthy *et al.* (2005) reported that *H. multicinctus* resistant banana hybrids *viz.*, H-201, H-02-08 and cultivars *viz.*, Anaikomban, Ambalakadali, Pisang Lilin and Eraichivazhai exhibited higher content of reducing sugar, orthodihydric phenol, bound phenol and phenylalanine ammonia lyase activity.

Sundararaju and Suba (2006) conducted pot culture experiment to understand the biochemical and molecular changes associated with resistance reaction of banana against *P. coffeae* and *M. incognita*. The highest protein concentration and increased peroxidase activity was observed in susceptible cvs. Nendran (AAB) and Robusta (AAA), whereas cvs. *M. balbisiana* (BBB), Karthobiumtham (ABB) and Pisang Jari Buaya (AA) showed minimum protein and peroxidase activity. But phenylalanine ammonia lyase (PAL) activity was significantly lower in cvs. Nendran and Robusta compared to other three varieties. The ratio between polyphenol oxidase and phenol was observed to be lower in resistant cvs. Karthobiumtham and *M. balbisiana* but much higher in Nendran and Robusta. The molecular analysis revealed higher rate of mRNA synthesis soon after nematode infection which contribute to the synthesis of these enzymes.

The reaction of 25 *Musa* hybrids to *P. coffeae* and their differential biochemical responses to nematode infection were studied under glasshouse conditions. Relatively higher enzyme activity of peroxidase (PO), polyphenol oxidase (PPO) and phenylalanine ammonia lyase (PAL) in the root was observed in tolerant hybrids than in susceptible ones (Damodaran *et al.*, 2007).

Devi *et al.* (2007a) studied the biochemical alterations in resistant banana accessions against *P. coffeae* and found that the activity of phenylalanine ammonia lyase (PAL) and total phenol in resistant accessions *viz.*, Karthobiumtham, M. balbisiana, Kanai Bansi, Bhimkol, Athiakol, Aittakol and Kechulepa was negatively correlated with lesion index of roots and corm.

Devi *et al.* (2007b) in another study conducted to understand the mechanism of resistance in banana cultivars against *P. coffeae* recorded maximum peroxidase and polyphenol oxidase activity in resistant banana cultivars like *M. balbisiana* (92.10 and 55.26 %), Kanai Bansi (88.90 and 53.34 %), Aittakol (80.50 and

48.30 %), Bhimkol (85.80 and 51.48 %) and Athiakol (92.00 and 55.20 %) than susceptible ones.

The investigation of the biochemical difference among the resistant and susceptible varieties of chickpea against *M. incognita* revealed that the moderately resistant varieties had higher degree of peroxidase enzyme activity than the susceptible ones (Chawla and Pankaj, 2007).

Kavitha *et al.* (2008b) studied the biochemical interactions of 24 phase I and 19 phase II generation banana hybrids against *P. coffeae* and recorded higher contents of total phenol, OD phenol and lignin in resistant hybrids than susceptible ones. Histological studies also confirmed the presence of more phenolic and lignified cell in the resistant/tolerant hybrids.

According to Das *et al.* (2011) the activities of enzymes like peroxidase, polyphenol oxidase and phenylalanine ammonia lyase and total phenol contents in banana roots were higher in *M. incognita* resistant genotypes like H-516 and H-531 than susceptible ones.

Kumar *et al.* (2012) studied the biochemical basis for resistance to mixed population of *P. coffeae* and *R. similis* in *in vitro* derived mutants of banana cv. Robusta (Cavendish- AAA) and Rasthali (Silk- AAB). They reported higher quantity of total phenol, tannin, lignin, peroxidase, polyphenol oxidase, phenylalanine ammonia lyase and ascorbic acid oxidase in resistant (Ro lm V4 6-1-1 and Si lm V4 10-5-3) and moderately resistant (Ro lm V4 6-2-1) mutants than the susceptible ones.

Vaganan *et al.* (2014) reported that the banana cultivars (Yangambi Km5 and Anaikomban) resistant to *P. coffeae* had significantly higher phenylalanine ammonia lyase (PAL) activity and total soluble and cell wall bound phenolics than in susceptible cultivars (Nendran and Robusta). The resistant cultivar responded strongly to the infection of the nematode by induction of several time higher PAL and cinnamyl alcohol dehydrogenase enzymes activities, soluble and wall bound phenolics and enrichment of lignin polymers in cell wall.

Das *et al.* (2014a) evaluated the total phenol content and activity of enzymes like peroxidase, polyphenol oxidase, and phenylalanine ammonia lyase of nineteen new synthetic banana phase II hybrids infected with *M. incognita.* The defense mechanism in response to nematode invasion indicated higher activities of total phenol, peroxidase, polyphenol oxidase, and phenylalanine ammonia lyase in resistant genotypes compared to susceptible ones.

Das *et al.* (2014b) also reported the role of biochemical contents like total phenol and enzymatic activity like PO, PPO and PAL in defense mechanism of nineteen new synthetic banana phase II hybrids in response to *H. multicinctus* invasion under pot conditions. Higher level of biochemical activities were detected in resistant and tolerant genotypes like H-531, H-02-34, H-03-05, H-03-13, H-03-17, H-04-12, H-04-24, NPH-02-01 and H-510 compared to susceptible ones

According to Holscher *et al.* (2014) secondary metabolites of *Musa* are the reason for the resistance of cultivars against *R. similis*. They detected a greater concentration of phenylphenalenone anigorufone in the root lesions of Yangambi Km5 (resistant cultivar) than the Grand Naine (susceptible cultivar). Anigorufone was reported as the most active nematostatic and nematicidal compound. When *R. similis* was exposed to anigorufone, large lipid–anigorufone complex droplets were observed to form in the bodies of *R. similis*, which resulted in the death of nematode.

Experiments conducted at National Research Centre for banana, Thiruchirapalli during 2014-15 on the biochemical mechanism of resistance of bananas to *P. coffeae* indicated that the activity of phenol oxidizing enzymes, stress related enzymes and the level of total phenols, lignin and tannins were higher even at 30 days after inoculation in resistant than in susceptible cultivars. The induction of the above said enzymes were more in the nematode challenged inoculated plants than in the unchallenged plants. The transcript levels of enzymes/proteins *viz.*, glutamine reductase, â- galactosidase and cinnamyl alcohol dehydrogenase were higher in banana roots of Anaikomban and Nendran infected with root lesion nematode (NRCB, 2015).

2.5. BIOCHEMICAL BASIS OF RESISTANCE IN OTHER CROPS AGAINST NEMATODES

Dropkin *et al.* (1969) studied the effect of exogenous plant growth substances in the hypersensitivity reaction of resistant tomato against *Meloidogyne* spp. The exogenous application of kinetin at 0.4 and 0.8 μM allowed 55 and 57 per cent of the nematodes to grow, reduced the incidence of necrosis by 32 and 31 per cent and increased gall formation to 73 and 65 per cent in the resistant variety compared to 4 per cent larval growth, 88 per cent induced necrosis and 29 per cent induced galls in the absence of plant growth regulatory substances. The studies revealed that the cytokinins could shift the response of the resistant plants towards the susceptible reaction.

Comparative study on host-parasite relationships of *M. incognita acrita* and *P. penetrans* on three closely related cultivars of tomato reported that the large number of larvae of these nematodes never penetrated the resistant variety of tomato due to some sort of inhibition provided by phenolic compounds. Chlorogenic acid was identified as the major phenolic compound in the roots after or before infection (Hung and Rohde, 1973).

Sawhney and Webster (1975) reported that combination of l-naphthalene-acetic acid (NAA) and kinetin increased the susceptibility of the tomato cultivar to *M. incognita*. When treated with the same combinations the resistant tomato variety produced gall, but only a few larvae developed to maturity. In this manner the resistance was not completely broken NAA or kinetin applied separately did not alter the resistant response to the root knot nematode

Veech and McClure (1977) observed a post infectional increase in concentration of terpenoid aldehydes in roots of cotton resistant to *M incognita* The susceptible varieties reacted by lowering the level of these compounds As gossypol and other terpenoid aldehydes were reported as toxic to insects and plant-pathogenic fungi, it was assumed that these compounds could reduce the population of nematodes

Noel and McClure (1978) noticed an increased specific activity of 6 phosphogluconate dehydrogenase and peroxidase enzymes in *M incognita* infested cotton They reported that the resistant cultivar (Clevewilt 6 3-5) showed higher enzyme activity than the susceptible one (M8)

According to Gibel (1982), active or post infectional resistance was based on plant tissue hypersensitivity to nematode infection The host-parasite interaction stimulated definite biochemical reactions in the host that caused histological changes i e host cell necrosis This necrosis form around the nematode, walling it off and either delaying development or causing the nematode to die especially in case of endoparasitic sedentary nematodes

A number of phenolic compounds including monohydroxy, dihydroxy and trihydroxy compounds, quinones and aromatic acids such as transcinnamic acid have been studied for their nematicidal activity and their effect on egg hatch of *M incognita* (Mahajan *et al*, 1985) Transcinnamic acid, pyrogallol, 2 OH napthoic acid and ethyl gallate were found to be highly toxic with mortality greater than 95 per cent and total suppression of hatching achieved by Naringenin

Mahajan *et al* (1992) tested a wide range of phenolic compounds for their nematicidal activity against *M incognita* Out of the 55 phenolic compounds tested, coumestrol, juglone, dihydroxy caffeic acid, 2, 6 dihydroxy benzoic acid, apigenin 7 o glucoside and genit aldehyde showed more than 98 per cent nematicidal activity

Ganguly *et al* (1993) found that the percentage of peroxidase activity in *M incognita* infested susceptible variety of tomato increased with time and infection Peroxidase activity in resistant variety increased in initial stage of infection, but decreased subsequently from 50 to 26 per cent The percentage of superoxide dismutase was found to be more in susceptible tomato (25-90 %) than the resistant variety (7-50 %)

Experiments conducted by Sirohi and Dasgupta (1993) revealed that the rate of increase of phenylalanine ammonia lyase and its activity between 24–72 h was relatively higher in inoculated resistant cowpea cultivar C-152 in contrast to its control as well as to inoculated and uninoculated susceptible cowpea cultivar Pusa do Fasli, connoting that the nematode-mediated biomolecular defense mechanism was activated as early as 24 h after inoculation in resistant cowpea cultivar Chlorogenic acid (CGA) turnover values were higher in between 24–72 h in inoculated resistant cultivar C-152 compared to inoculated susceptible cultivar Pusa do Fasli, implying that the onset of faster rate of PAL in inoculated resistant C 152 preceded highest concentration of CGA which was not the case in Pusa do Fasli, indicating an early, faster onset or completion of lignification in C-152 as compared to Pusa do Fasli

Studies were conducted by Mohanthy *et al* (1995) on the biochemical changes of two brinjal varieties *viz* Pusa purple long (susceptible) and Ghatia white (resistant) inoculated with *M incognita* Five amino acids like L cystine, L-serine, L-tryptophan, L leucine and L-isoleucine were found to be common in both the varieties Higher concentration of various amino acids and amides were detected in each variety upon nematode inoculation except L-tryptophan The content of chlorogenic acid, total sugar, peroxidase and catalase activities were higher in inoculated samples than their healthy counterparts But, the catalase activity was reduced in inoculated susceptible sample

Biochemical alterations brought about in *Abelmoschus esculentus* as a result of *M incognita* infection was studied in roots uprooted after 30 60 and 90 days of inoculation Quantitative analysis for different metabolites in both highly susceptible (Pusa Sawani) and less susceptible (Punjab 7) cultivars showed reducing sugars proteins total free amino acids, proline, phenols, ascorbic acid, enzymes, nitrogen and sodium excepting total sugars, non reducing sugars, phosphorus and potassium increased in diseased roots of both okra cultivars over their healthy counterparts (Sharma and Trivedi, 1996)

Pankaj *et al* (2001) investigated the specific activity of 4- hydroxycinnamic acid CoA Ligase as a substrate at an early stage of infection with *M incognita* in both susceptible (Pusa Ruby) and resistant (Nemamukt and Hisar Lalit) cultivars of tomato The activity was higher in resistant cultivars Nemamukt (18 0 to 150 8 %) and Hisar Lalit (34 2 to 162 7 %) at different time intervals compared to susceptible cv Pusa Ruby (15 0 to 40 0 %) The number of isozymes increased from 3 to 6 in resistant cultivars but remained unchanged in susceptible one The relative specific activity of the enzyme was 15 and 20-fold during the purification process in resistant and susceptible cultivars, respectively The enzyme activity was maximum at 25–30°C with pH ranging from 7 5 to 8 5 and p coumaric acid was judged to be the best substrate

Swain *et al* (2004) conducted studies on sequential development of phenylalanine ammonia lyase, polyphenol oxidase, phenol and lignin like polymers in differential host plants (cotton and tobacco) and their susceptible counter control According to them, the rapid and early accumulation of the biochemicals occurred in all the host differentials than their controls

Gopinatha *et al* (2004) studied the histopathology of root knot infected moderately resistant and susceptible tomato plants The results revealed that the cultivars with moderate resistance manifested higher concentration of total insoluble polysaccharides, nucleic acids and total protein when compared to their healthy counterparts

An increased activity of antioxidants like peroxidase, superoxide dismutase, polyphenol oxidase, esterase, monohydro ascorbate reductase, dehydro ascorbate reductase and decreased activity of catalase were noted in *M incognita* resistant tomato cultivars (Hisar Lalit, PNR- 7) than susceptible ones (Punjab Varkha Bahar 1 and Punjab Varkha Bahar- 2) The intensity of isozyme bands of peroxidase and esterase was more in resistant than the susceptible ones and an additional band was obtained in the isozyme banding pattern of esterase in the resistant genotypes (Chawla *et al* , 2013)

Materials and methods

3. MATERIALS AND METHODS

The study entitled "Response of selected banana varieties to root knot nematode *Meloidogyne incognita* (Kofoid and White)" was carried out in the Department of Agricultural Entomology, College of Horticulture, Vellanikkara and Banana Research Station, Kannara during 2014-2015 to screen the selected banana varieties against root knot nematode and to elucidate the biochemical bases of resistance

3 1 PREPARATION OF DENEMATIZED POTTING MIXTURE

Potting mixture was prepared by mixing sieved field soil, sand and well decomposed farm yard manure in the ratio 1 1 1 and denematized with three per cent formaldehyde at 50 ml for 200 kg potting mixture Holes were made on the heap of potting mixture to pour formaldehyde solution and the heap was tightly covered with polythene sheets After one week, polythene sheets were removed and the potting mixture was raked well and covered for one more week The polythene sheets were removed and the potting mixture was spread on the floor to remove the residues of formaldehyde solution Samples were taken randomly from the treated potting mixture to examine the presence of plant parasitic nematodes This denematized potting mixture was used for conducting pot culture experiment

3 2 Maintenance of pure culture of root knot nematode

The cuttings of coleus plants were used for the maintenance of root knot nematode culture Coleus stem cuttings were planted in pots of size 25 cm diameter which were filled with denematized potting mixture The egg masses obtained from the infested roots of banana were isolated and confirmed the species as *M incognita* to get the pure culture of nematodes The potted coleus plants were inoculated with one day old second stage juveniles of *M incognita* emerged from the egg masses

Repotting and inoculation was done periodically for multiplying root knot nematodes for the experiment

3 3 POT CULTURE EXPERIMENT

Banana varieties from the germplasm collection of Banana Research station, Kannara were selected for screening studies Twenty five varieties comprising of nine exotic hybrids, six Indian varieties, nine exotic varieties and a highly susceptible check (Robusta) were studied for their response to *M incognita*

3 3 1 Raising potted plants

Polythene bags of size 80 x 35 cm were filled with 30 kg denematized potting mixture for raising banana plants Suckers of uniform age (three months) obtained from Banana Research Station (BRS), Kannara, were used for carrying out the pot culture experiment Plants were maintained as per Package of Practices recommendation of Kerala Agricultural University (KAU 2011) Regular removal of dried leaves and weeds were also done to keep the plants and the surrounding field clean

3 3 2 Design and treatments

The experiment plot was laid out at Banana Research Station, Kannara in Completely Randomized Design with 25 treatments and three replications (Plate 3) The treatments were as follows

Table 1. Details of banana varieties/ hybrids evaluated

Treatments		Genomic group	Details of varieties
T_1	FHIA -1	AAAB	Exotic hybrid
T_2	FHIA 3	AABB	Exotic hybrid
T_3	FHIA -17	AAAA	Exotic hybrid
T_4	FHIA -18	AAAB	Exotic hybrid
T_5	TMP 2829	AB	Exotic hybrid
T_6	SH – 3640	AAAB	Exotic hybrid
T_7	SH –3436 6	AAAA	Exotic hybrid
T_8	SH –3436-9	AAAA	Exotic hybrid
T_9	TMB × 5295-1	AAAB	Exotic hybrid
T_{10}	Udayam	ABB	Indian variety
T_{11}	Dudhsagar	AAB	Indian variety
T_{12}	Karpooravally Dwarf	ABB	Indian variety
T_{13}	Mysore Ethan	AAB	Indian variety
T_{14}	Sugandhi	AAB	Indian variety
T_{15}	Manjeri Nendran II	AAB	Indian variety
T_{16}	Yangambi Km5	AAA	Exotic variety
T_{17}	Big Ebanga	AAB	Exotic variety
T_{18}	Bangrier	ABB	Exotic variety
T_{19}	Pisang Nangka	AAB	Exotic variety
T_{20}	Popoulu	AAB	Exotic variety
T_{21}	Pisang Madu	AA	Exotic variety
T_{22}	Pisang Ceylan	AAB	Exotic variety
T_{23}	Pisang Jari Buaya	AA	Exotic variety
T_{24}	Pisang Buntal	AA	Exotic variety
T_{25}	Robusta	AAA	Susceptible check

Plate 3 Lay out of the experiment

3.3.3 Extraction of second stage juveniles of *M. incognita* for inoculation

Extraction of second stage juveniles of root knot nematode was done by Modified Baermann Funnel Technique (Schindler, 1961). Heavily infested plants from the culture pots were uprooted carefully and washed with water to remove soil particles adhering to the roots. The egg masses from galled roots were collected using forceps. The second stage juveniles were obtained by keeping the egg masses over two layers of tissue paper supported on a wire mesh which in turn was placed over a Petri dish containing water just enough to touch the egg masses. After hatching, the juveniles settled at the bottom of the Petri plate. Several such sets were kept for getting the required number of second stage juveniles. Hatched juveniles from each Petri plate were collected in a beaker and used for inoculation.

3.3.4 Inoculation of nematodes

Population of the nematodes in the suspension was assessed after the extraction of nematodes. The nematode suspension collected in the beaker was made up to a constant volume by adding water. The nematode suspension was thoroughly mixed by blowing air with a pipette. An aliquot of 1 ml was pipetted out into a counting dish and the number of nematodes present was counted under a stereoscopic microscope. The process was repeated four times and average population per milliliter was estimated. The total population of nematodes present in the suspension was estimated by multiplying the average population per ml with total volume of nematode suspension. Each banana plant was inoculated with 100 ml suspension containing 50,000 second stage juveniles of root knot nematodes after the plants had established i.e. 45 days after planting. At the time of inoculation, the suspension was thoroughly mixed by blowing air with a pipette to get uniform distribution of nematodes. The suspension was then poured into the root zone of the plants by making holes of about five cm depth on all sides of the plant using a glass rod. After pouring the entire suspension, the holes were covered with thin layer of soil.

3.4 BIOCHEMICAL STUDIES

Biochemical basis of resistance of banana varieties to root knot nematode were estimated by analyzing the activity of peroxidase (PO), polyphenol oxidase (PPO), phenylalanine ammonia lyase (PAL) and the total phenol content after three months of inoculation of *M. incognita*. To estimate these parameters, root samples were randomly collected from each plant and washed thoroughly to remove the adhering debris and soil particles. Excess water was removed using a tissue paper and kept in a labeled polythene cover. The root samples were transported from field to lab in an ice box to maintain low temperature and this temperature was maintained until the end of the experiment.

3.4.1 Peroxidase (PO) activity

The peroxidase activity of banana roots were analysed as per the procedure described by Malik and Singh (1980).

The enzyme was extracted by grinding one gram fresh banana roots of each variety in three ml of 0.1 M phosphate buffer with pH 7 in a pre cooled mortar and pestle. The homogenate obtained was centrifuged at 10,000 rpm at 5 °C for 15 minutes and the supernatant was used as enzyme source. Three milliliters of 0.1 M phosphate buffer solution, 0.05 ml of 20 mM guaiacol solution, 0.1 ml enzyme extract and 0.03 ml of 12.3 mM hydrogen peroxide solution were pipetted out into a cuvette and mixed well. Readings were taken at 470 nm in spectrophotometer (Model 4001/4 Thermo Spectronic, Thermo Electronic Corporation, USA) such that the absorbance was increased by 0.05. The time required in minutes (t) for increase in the absorbance by 0.1 was noted with the help of a stop watch.

$$\text{Enzyme activity units/gram} = \frac{3.18 \times 0.1}{6.39 \times \Delta t \times 0.1} = \frac{500}{\Delta t}$$

3.4.2 Polyphenol oxidase (PPO) activity

Polyphenol oxidase activity in banana roots was analysed as per the procedure by Esterbaner *et al.* (1977).

The enzyme was extracted by macerating 0.5 g of fresh banana roots with a mortar and pestle in about five milliliter medium containing three milliliter 50 mM Tris HCl (pH 7.2), one milliliter 0.4 M Sorbitol and one milliliter 10 mM NaCl. Then supernatant was obtained by centrifuging this homogenate at 20,000 rpm for 10 minutes. The enzyme extract of 0.2 ml was added to a cuvette containing 2.5 ml of 0.1 M phosphate buffer (pH 6.5) and 0.3 ml of 0.01 M catechol solution and readings were recorded using spectrophotometer (Model 4001/4 Thermo Spectronic, Thermo Electronic Corporation, USA) at 495 nm. The change in absorbance was recorded for every 30 seconds up to five minutes.

$$\text{Enzymatic units in the test} = K \times \left(\frac{\Delta x}{\min}\right)$$

Where K is 0.272 for catechol oxidase and Δx was the decrease in absorbance.

3.4.3 Phenylalanine ammonia lyase (PAL) activity

Phenylalanine ammonia lyase activity was determined spectrophotometrically as described by Brueske (1980).

The enzyme extract was obtained by grinding 0.5 g fresh banana roots in five milliliter of cold 25 mM borate buffer (pH 8.8) containing 5 mM mercaptoethanol and centrifuging the homogenate at 12,000 rpm for 20 minutes. The supernatant of 0.2 ml was added in to a test tube containing 0.5 ml borate buffer and 1.3 ml of distilled water. The reaction was initiated by adding 1 ml L-Phenylalanine (0.1 M) solution and incubated for 45 minutes. The reaction was stopped by adding 0.5 ml of 1 M trichloroacetic acid. The absorbance was measured at 290 nm in Spectroquant pharo 300 UV VIS spectrophotometer against blank The reaction rate was expressed as µmol *trans*- cinnamic acid formed per gram of fresh weight as determined from *trans*- cinnamic acid standard graph

3 4 4 Total phenol content

Total phenol was estimated with the folin-ciocalteau reagent using method described by Malik and Singh (1980)

The homogenate was prepared by grinding 0 5 g fresh banana roots with 10 ml of 80 per cent ethanol This homogenate was centrifuged at 10,000 rpm for 20 minutes and the supernatant was collected in a test tube and kept in a hot water bath to evaporate the ethanol The pellets thus obtained were dissolved in five milliliter distilled water Folin ciocalteau reagent (0 5 ml) was added into a test tube containing 0 2 ml of sample solution and 2 8 ml of distilled water and then heated for three minutes Two milliliter of 20 per cent Na_2CO_3 solution was added to the test tube and the absorbance was measured at 650nm using spectrophotometer (Model-4001/4 Thermo Spectronic, Thermo Electronic Corporation, USA) The concentration of phenols in the sample was estimated by using a standard solution of catechol and total phenol was expressed as mg g^{-1} of fresh weight Calculation carried out by the given formula

$$\frac{\text{Test sample absorbance}}{\text{Standard solution absorbance}} \times \frac{\text{Concentration of standard solution}}{\text{Weight of Sample}}$$

3 5 OBSERVATIONS

Banana plants were allowed to grow for a period of six months after inoculation The following biometric characters were recorded at monthly intervals

a) Height of the plant
b) Girth of the pseudostem

c) Number of leaves

Six months after inoculation the plants were uprooted and following observations were taken

a) Nematode population in 250 g soil
b) Nematode population in 20 g roots
c) Number of root knots in 20 g roots
d) Root knot index

3 5 1 Estimation of nematode population from soil

Six months after the inoculation of *M incognita* the plants were uprooted and the population of nematodes in the soil was estimated A composite sample of 250 g of soil was collected from the root zone of each banana plant grown in polythene bag and processed for extracting the nematodes Cobb's decanting and sieving technique (Cobb, 1918) was followed to extract the nematodes from soil samples from different treatments The residue obtained from 100, 200 and 325 mesh sieves were collected in a 250 ml beaker The residue thus collected was cleared by Modified Baerman Funnel technique (Schindler, 1961) The nematode population was assessed with the help of a stereoscopic microscope

3 5 2 Estimation of root knots from 20 g root

Banana plants were carefully lifted by removing the polythene bag and the loose soil To remove the adhering soil particles roots were washed gently with water Twenty gram roots was randomly taken and pressed gently between the folds of blotting paper to remove excess water The number of galls in 20 g of root sample was counted

3 5 3 Root knot ındex

Based on the number of galls counted, the root knot index was worked out by ratıng on a 1-5 scale and the varıetıes were grouped as hıghly resıstant, resıstant, moderately resıstant, susceptıble and hıghly susceptıble (Gıtanjalıdevı *et al* 2014)

Table 2. Classificatıon of resıstance based on root knot index and number of root knots

Sl No	Root knot ındex	No of galls/ plant	Reactıon
1	1	No gall	Hıghly resıstant
2	2	1-10 galls	Resıstant
3	3	11-30 galls	Moderately resıstant
4	4	31-100 galls	Susceptıble
5	5	101 and above	Hıghly susceptıble

3 5 4 Estımatıon of nematode populatıon from root

After countıng the number of galls, the same root samples were used for extractıng the second stage juvenıles usıng Modıfied Baermann Funnel technıque (Schındler, 1961) The root samples were cut ın to small pıeces and placed over two layers of tıssue paper supported on a wire mesh whıch ın turn was placed over a Petrı dısh Every 24 h the nematode suspensıon ın the Petrı plate was collected ın a beaker Thıs was contınued tıll no nematode was obtaıned The nematode suspensıon thus obtaıned was pooled together and the populatıon of nematodes was assessed under a stereoscopıc mıcroscope

3 6 STATISTICAL ANALYSIS

Data collected from the study were analysed by statistical method for CRD and ANOVA Analysis of variance was done using statistical software 'MSTAT' and the mean values were compared by DMRT (Duncan, 1951) Pearsons correlation test was done using the statistical package, SPSS (Statistical Package for Social Sciences) to compare the different parameters

Results

4 RESULTS

The results of the study entitled "Response of selected banana varieties to root knot nematode *Meloidogyne incognita* (Kofoid and White)" conducted at College of Horticulture, Vellanikkara and Banana Research station, Kannara are presented in this chapter

4 1 SCREENING OF BANANA VARIETIES AGAINST ROOT KNOT NEMATODE

4 1 1 Biometric characters of banana

The biometric characters *viz*, plant height, pseudostem girth, number of leaves of twenty five banana varieties were observed at monthly intervals from the time of inoculation till uprooting (six months after inoculation) The varieties selected for the study are mentioned in 3 3 2

4 1 1 1 Height of the plant

The observations on height of the banana plants are presented in Table 3 The results indicated that all the varieties showed an increasing trend in terms of height and there was significant variation existed among the varieties The mean height of the plants at the time of inoculation and at the time of uprooting ranged from 24 55 cm to 48 76 cm and 52 07 cm to 74 93 cm, respectively The highest increase in height was observed from the variety Karpooravally Dwarf (155 71 %) It was only 25 99 cm at the time of inoculation and reached 66 46 cm at the time of uprooting This was followed by Popoulu and FHIA-3, with 29 21 and 26 92 cm height, respectively at the time of inoculation and 71 54 and 65 19 cm, respectively at the time of uprooting which showed a per cent increase of 144 93 and 142 14 for Popoulu and FHIA-3, respectively The lowest increase in plant height was observed in

Yangambi Km5 (30 85 %) followed by Pisang Buntal (34 58 %) and Robusta (35 24 %) The increase in height of all the other varieties ranged from 40 74 to 141 37 per cent

4 1 1 2 Girth of pseudostem

Statistical analysis of the data indicated that there was significant variation in the girth of pseudostem of different varieties (Table 4) The highest increase of 96 30 per cent in pseudostem girth was observed in FHIA-1 and FHIA-3 Both recorded 11 43 cm at the time of inoculation and reached 22 44 cm at the time of uprooting These were followed by Popoulu and Udayam with 81 11 and 66 67 per cent increase respectively The lowest increase in pseudostem girth was observed in Robusta with 14 29 per cent followed by SH 3640 with 18 19 per cent These varieties recorded 17 78 and 18 63 cm respectively at the time of inoculation and reached 20 32 and 22 01 cm, respectively at the time of uprooting Increase in pseudostem girth of rest of the varieties ranged from 22 93 to 65 92 per cent

4 1 1 3 Number of leaves

Total number of leaves produced from the time of inoculation to the time of uprooting in each month is given in Table 5 Pisang Ceylan recorded the highest increase of 563 57 per cent and susceptible check Robusta with lowest increase of 233 34 per cent in leaf production within six months At the time of inoculation Pisang Ceylan recorded only 3 67 leaves, whereas Robusta recorded 5 00 leaves per plant When the plants were uprooted, Pisang Ceylan and Robusta produced 24 33 and 16 66 respectively All other varieties recorded a per cent increase of 235 27 and 541 68 in total number of leaves

Table 3. Height of banana varieties

Treatments	Height of the plants (cm) (Mean of three replications)							Per cent increase
	At the time of inoculation	Months after inoculation						
		1	2	3	4	5	6	
T_1 - FHIA -1	35 56 ^{cdefg}	40 64 ^{cdefg}	49 10 ^{bcd}	58 42 ^{abcd}	63 50 ^{abc}	68 58 ^{ab}	71 12 ^{ab}	100 00
T_2 FHIA 3	26 92 ^{hij}	27 51 ^{j}	38 10 ^{jk}	50 37 ^{efgh}	55 88 ^{efghij}	61 63 ^{defg}	65 19 ^{cde}	142 14
T_3 - FHIA -17	45 72 ^{ab}	46 72 ^{bcd}	48 26 ^{bcde}	55 62 ^{bcdef}	59 69 ^{bcdefg}	62 14 ^{defg}	64 34 ^{cdefg}	40 74
T_4 - FHIA -18	40 81 ^{bcde}	44 02 ^{bcde}	46 14 ^{bcdefgh}	55 11 ^{cdef}	58 67 ^{cdefg}	64 34 ^{bcde}	71 96 ^{ab}	76 34
T_5 - TMP 2829	39 79 ^{bcde}	44 87 ^{bcd}	49 53 ^{bcd}	55 79 ^{abcdef}	59 69 ^{bcdefg}	61 38 ^{defg}	66 46 ^{bcd}	67 02
T_6 - SH – 3640	35 56 ^{cdefg}	42 75 ^{cdef}	47 41 ^{bcdef}	56 55 ^{abcde}	59 69 ^{bcdefg}	63 07 ^{bcdef}	69 42 ^{abc}	95 24
T_7 SH –3436 6	34 71 ^{cdefg}	35 56 ^{fghi}	41 48 ^{fghijk}	47 58 ^{gh}	51 14 ^{ijk}	54 61 ^{ijk}	64 77 ^{cdef}	86 58
T_8 - SH –3436 9	31 92 ^{fghij}	36 40 ^{efghi}	40 21 ^{hijk}	48 00 ^{gh}	51 90 ^{hijk}	56 72 ^{ghijk}	60 96 ^{defgh}	90 98

(Contd)

In a column, values superscripted by a common letter do not differ significantly in DMRT (P=0 05)

Treatments	Height of the plants (cm) (Mean of three replications)							Per cent increase
	At the time of inoculation	Months after inoculation						
		1	2	3	4	5	6	
T_9 - TMB × 5295-1	30 48 ^{ghij}	35 56 ^{fghi}	37 67 ^{jk}	49 10 ^{fgh}	55 03 ^{fghijk}	59 26 ^{efghij}	63 50 ^{defg}	108 33
T_{10} – Udayam	40 64 ^{bcde}	44 45 ^{bcd}	47 41 ^{bcdef}	53 84 ^{cdefg}	55 88 ^{efghij}	59 26 ^{efghij}	63 07 ^{defg}	55 21
T_{11} – Dudhsagar	30 05 ^{ghij}	35 13 ^{fghij}	40 64 ^{ghijk}	53 42 ^{cdefgh}	57 15 ^{defghi}	60 96 ^{defgh}	65 19 ^{cde}	116 91
T_{12} - Karpooravally Dwarf	25 99 ^{ij}	28 78 ^{ij}	36 83 ^{k}	46 56 ^{h}	53 76 ^{ghijk}	61 38 ^{defg}	66 46 ^{bcd}	155 71
T_{13} - Mysore Ethan	33 44 ^{efghi}	38 94 ^{defgh}	41 48 ^{fghijk}	47 83 ^{gh}	50 37 ^{jk}	54 61 ^{ijk}	58 84 ^{gh}	75 95
T_{14} – Sugandhı	34 20 ^{defgh}	38 94 ^{defgh}	46 99 ^{bcdefg}	57 57 ^{abcd}	61 80 ^{abcde}	68 07 ^{abc}	74 93 ^{a}	119 05
T_{15} - Manjeri Nendran II	34 88 ^{cdefg}	44 70 ^{bcd}	49 95 ^{bcd}	60 11 ^{abc}	66 04 ^{a}	70 27 ^{a}	73 66 ^{a}	111 17
T_{16} Yangambi Km5	39 79 ^{bcde}	42 50 ^{cdef}	43 60 ^{defghij}	46 73 ^{h}	48 85 ^{k}	51 64 ^{k}	52 07 ^{i}	30 85
T_{17} - Big Ebanga	30 56 ^{ghij}	33 86 ^{ghij}	42 33 ^{efghijk}	51 64 ^{defgh}	56 72 ^{defghi}	60 11 ^{defghi}	63 50 ^{defg}	107 76

(Contd)

In a column, values superscripted by a common letter do not differ significantly in DMRT (P=0 05)

Treatments	Height of the plants (cm) (Mean of three replications)							Per cent increase
	At the time of inoculation	Months after inoculation						
		1	2	3	4	5	6	
T_{18} – Bangrier	24 55 ^{j}	32 17 ^{hij}	39 37 ^{ijk}	47 75 ^{gh}	50 20 ^{jk}	54 18 ^{jk}	59 26 ^{fgh}	141 37
T_{19} - Pisang Nangka	39 54 ^{bcdef}	44 02 ^{bcde}	49 10 ^{bcd}	58 24 ^{abcd}	62 23 ^{abcd}	62 65 ^{cdef}	63 50 ^{defg}	60 60
T_{20} – Popoulu	29 21 ^{ghij}	35 13 ^{fghij}	41 06 ^{fghijk}	53 34 ^{cdefgh}	60 11 ^{abcdef}	65 61 ^{abcd}	71 54 ^{ab}	144 93
T_{21} - Pisang Madu	42 33 ^{abc}	50 80 ^{ab}	52 74 ^{ab}	56 64 ^{abcde}	57 23 ^{cdefgh}	58 42 ^{fghij}	59 69 ^{efgh}	41 00
T_{22} - Pisang Ceylan	48 76 ^{a}	56 72 ^{a}	58 42 ^{a}	62 40 ^{ab}	66 20 ^{a}	68 41 ^{abc}	71 96 ^{ab}	47 57
T_{23} Pisang Jari Buaya	46 14 ^{ab}	51 64 ^{ab}	57 57 ^{a}	62 65 ^{a}	65 44 ^{ab}	68 58 ^{ab}	72 81 ^{a}	57 80
T_{24} - Pisang Buntal	45 29 ^{ab}	48 17 ^{bc}	52 07 ^{abc}	55 88 ^{abcdef}	57 99 ^{cdefgh}	59 94 ^{defghij}	60 96 ^{defgh}	34 58
T_{25} – Robusta	41 31 ^{abcd}	44 02 ^{bcde}	45 72 ^{cdefghi}	51 64 ^{defgh}	54 18 ^{fghijk}	55 45 ^{hijk}	55 88 ^{hi}	35 24

In a column, values superscripted by a common letter do not differ significantly in DMRT (P=0 05)

Table 4. Pseudostem girth of banana varieties

Treatments	Pseudostem girth (cm) (Mean of three replications)							Per cent increase
	At the time of inoculation	Months after inoculation						
		1	2	3	4	5	6	
T_1 - FHIA -1	11 43 ^{f}	12 70 ^{h}	14 22 ^{i}	15 32 ^{gh}	17 10 ^{defgh}	19 89 ^{abcde}	22 44 ^{ab}	96 30
T_2 - FHIA -3	11 43 ^{f}	14 39 ^{efgh}	16 51 ^{defghi}	18 54 ^{abcdef}	20 74 ^{ab}	22 01 ^{a}	22 44 ^{ab}	96 30
T_3 - FHIA -17	14 39 ^{cdef}	16 93 ^{bcde}	18 20 ^{abcde}	19 30 ^{abcd}	20 57 ^{ab}	21 59 ^{ab}	21 59 ^{abcd}	49 99
T_4 - FHIA -18	17 36 ^{abc}	18 63 ^{ab}	19 47 ^{ab}	19 98 ^{ab}	20 15 ^{abc}	21 16 ^{abc}	22 86 ^{ab}	31 71
T_5 TMP 2829	15 66 ^{abcd}	17 36 ^{abcd}	18 63 ^{abcd}	19 90 ^{ab}	20 15 ^{abc}	21 16 ^{abc}	22 01 ^{abc}	40 53
T_6 SH – 3640	18 63 ^{a}	19 90 ^{a}	20 15 ^{a}	20 74 ^{a}	21 17 ^{a}	21 59 ^{ab}	22 01 ^{abc}	18 19
T_7 - SH –3436 6	13 55 ^{def}	15 07 ^{defgh}	16 34 ^{defghi}	16 76 ^{defgh}	17 36 ^{defgh}	18 62 ^{bcdef}	19 47 ^{cdefg}	43 76
T_8 - SH –3436 9	13 97 ^{def}	15 24 ^{defgh}	16 93 ^{cdefgh}	17 78 ^{bcdefg}	18 88 ^{abcdef}	19 72 ^{abcde}	19 98 ^{abcdefg}	43 03

(Contd)

In a column, values superscripted by a common letter do not differ significantly in DMRT (P=0 05)

Treatments	Pseudostem girth (cm) (Mean of three replications)							Per cent increase
	At the time of inoculation	Months after inoculation						
		1	2	3	4	5	6	
T_9 - TMB × 5295-1	11 43 ^{i}	13 97 ^{fgh}	15 49 ^{fghi}	16 51 ^{efgh}	16 51 ^{efgh}	17 35 ^{def}	18 97 ^{defg}	65 92
T_{10} – Udayam	12 70 ^{def}	13 97 ^{fgh}	15 24 ^{ghi}	16 26 ^{fgh}	17 02 ^{defgh}	18 62 ^{bcdef}	21 17 ^{abcde}	66 67
T_{11} – Dudhsagar	14 39 ^{cdef}	15 32 ^{defgh}	16 17 ^{efghi}	17 10 ^{cdefgh}	17 53 ^{cdefgh}	19 05 ^{abcde}	22 01 ^{abc}	52 93
T_{12} Karpooravally Dwarf	13 55 ^{def}	14 82 ^{defgh}	15 92 ^{efghi}	16 34 ^{fgh}	17 27 ^{defgh}	19 47 ^{abcde}	21 17 ^{abcde}	56 26
T_{13} - Mysore Ethan	11 85 ^{f}	13 46 ^{gh}	14 14 ^{i}	14 64 ^{h}	14 98 ^{h}	15 83 ^{f}	16 00 ^{h}	34 99
T_{14} – Sugandhi	13 55 ^{def}	15 24 ^{defgh}	16 51 ^{defghi}	17 44 ^{bcdefg}	18 20 ^{bcdefg}	19 30 ^{abcde}	19 98 ^{abcdefg}	47 51
T_{15} - Manjeri Nendran II	13 55 ^{def}	14 39 ^{efgh}	15 07 ^{ghi}	16 33 ^{fgh}	17 10 ^{defgh}	18 11 ^{cdef}	18 37 ^{efgh}	35 64
T_{16} - Yangambi Km5	13 55 ^{def}	14 73 ^{defgh}	15 07 ^{ghi}	15 32 ^{gh}	15 92 ^{gh}	17 18 ^{ef}	17 36 ^{gh}	28 14
T_{17} - Big Ebanga	12 28 ^{ef}	13 72 ^{gh}	14 90 ^{ghi}	15 49 ^{gh}	16 17 ^{gh}	17 44 ^{def}	17 61 ^{fgh}	43 46

(Contd)

In a column values superscripted by a common letter do not differ significantly in DMRT (P=0 05)

Treatments	Pseudostem girth (cm) (Mean of three replications)							Per cent increase
	At the time of inoculation	Months after inoculation						
		1	2	3	4	5	6	
T_{18} – Bangrier	13 12 ^{def}	14 39 ^{efgh}	15 41 ^{fghi}	15 83 ^{gh}	16 26 ^{fgh}	17 10 ^{ef}	17 61 ^{fgh}	34 19
T_{19} - Pisang Nangka	13 97 ^{def}	15 49 ^{cdefg}	16 09 ^{efghi}	16 76 ^{defgh}	17 78 ^{cdefg}	19 30 ^{abcde}	19 47 ^{cdefg}	39 39
T_{20} – Popoulu	12 11 ^{ef}	14 48 ^{efgh}	16 43 ^{defghi}	17 44 ^{bcdefg}	18 88 ^{abcdef}	21 42 ^{ab}	21 93 ^{abc}	81 11
T_{21} - Pisang Madu	15 24 ^{bcde}	16 51 ^{bcdef}	17 78 ^{abcdef}	18 54 ^{abcdef}	19 05 ^{abcde}	19 89 ^{abcde}	19 90 ^{bcdefg}	30 56
T_{22} - Pisang Ceylan	17 36 ^{abc}	18 46 ^{ab}	19 30 ^{abc}	19 64 ^{abc}	20 49 ^{ab}	21 16 ^{abc}	21 34 ^{abcd}	22 93
T_{23} Pisang Jari Buaya	12 70 ^{def}	13 63 ^{gh}	14 73 ^{hi}	15 83 ^{gh}	17 02 ^{defgh}	18 28 ^{cdef}	18 71 ^{defgh}	47 33
T_{24} Pisang Buntal	14 39 ^{cdef}	15 58 ^{cdefg}	17 19 ^{bcdefg}	19 13 ^{abcde}	19 64 ^{abcd}	20 99 ^{abc}	21 00 ^{abcde}	45 87
T_{25} – Robusta	17 78 ^{ab}	18 12 ^{abc}	18 71 ^{abcd}	18 80 ^{abcdef}	19 56 ^{abcd}	20 32 ^{abcd}	20 32 ^{abcdef}	14 29

In a column, values superscripted by a common letter do not differ significantly in DMRT (P=0 05)

Table 5. Number of leaves of banana varieties

Treatments	Number of banana leaves (Mean of three replications)							Per cent increase
	At the time of inoculation	Months after inoculation						
		1	2	3	4	5	6	
T_1 FHIA -1	5 00^{abcd}	8 00^{bcd}	11 67^{bcd}	16 67^{c}	18 67^{bc}	21 67^{cd}	23 00^{c}	360 00
T_2 FHIA 3	5 67^{ab}	9 00^{d}	11 67^{bcd}	16 33^{cd}	18 00^{cde}	19 67^{ef}	20 67^{ef}	264 69
T_3 - FHIA -17	4 67^{bcde}	7 67^{cde}	10 67^{efg}	16 00^{cde}	18 00^{cde}	19 67^{ef}	20 67^{ef}	342 83
T_4 - FHIA -18	5 00^{abcd}	8 67^{ab}	13 33^{a}	19 33^{a}	21 00^{a}	23 00^{ab}	24 33^{b}	386 66
T_5 - TMP 2829	3 67^{ef}	8 33^{abc}	11 33^{cde}	16 67^{c}	18 67^{bc}	20 67de	22 00^{cd}	499 95
T_6 SH – 3640	5 33^{abc}	9 00^{a}	12 33^{b}	16 67^{c}	18 67^{bc}	20 67de	21 66de	306 28
T_7 - SH –3436 6	5 00^{abcd}	8 67^{ab}	11 67^{bcd}	15 67^{cdef}	17 67^{cdef}	19 67^{ef}	20 67^{ef}	313 34
T_8 - SH –3436-9	4 67^{bcde}	7 67^{cde}	10 00^{gh}	14 00^{gh}	15 33^{g}	16 33^{hi}	17 33^{jk}	271 39

(Contd)

In a column, values superscripted by a common letter do not differ significantly in DMRT (P=0 05)

Treatments	Number of banana leaves (Mean of three replications)							Per cent increase
	At the time of inoculation	Months after inoculation						
		1	2	3	4	5	6	
T_9 - TMB × 5295-1	4 00 ^{def}	7 67 ^{cde}	11 33 ^{cde}	18 33 ^{ab}	20 67 ^{a}	22 66 ^{bc}	24 67 ^{ab}	516 68
T_{10} – Udayam	4 66 ^{bcde}	7 66 ^{cde}	10 33 ^{fgh}	15 00 ^{efg}	17 00 ^{ef}	18 33 ^{g}	19 33 ^{gh}	314 25
T_{11} – Dudhsagar	4 00 ^{def}	7 33 ^{def}	10 66 ^{efg}	16 33 ^{cd}	18 67 ^{bc}	20 00 ^{ef}	21 00 ^{def}	425 00
T_{12} - Karpooravally Dwarf	3 33 ^{f}	6 66 ^{fg}	9 66 ^{hi}	15 33 ^{def}	17 33 ^{def}	19 00 ^{fg}	20 33 ^{fg}	510 05
T_{13} - Mysore Ethan	4 00 ^{def}	6 33 ^{g}	8 66 ^{j}	13 00 ^{hi}	14 66 ^{g}	16 33 ^{hi}	17 33 ^{jk}	333 33
T_{14} – Sugandhi	4 00 ^{def}	8 00 ^{bcd}	11 66 ^{bcd}	18 33 ^{ab}	21 33 ^{a}	24 00 ^{a}	25 66 ^{a}	541 68
T_{15} Manjeri Nendran II	5 33 ^{abc}	8 66 ^{ab}	11 66 ^{bcd}	16 66 ^{c}	18 66 ^{bc}	19 66 ^{ef}	20 66 ^{ef}	287 53
T_{16} – Yangambi Km5	4 33 ^{cdef}	7 66 ^{cde}	11 00 ^{def}	15 00 ^{efg}	17 00 ^{ef}	18 33 ^{g}	19 33 ^{gh}	346 18
T_{17} - Big Ebanga	4 33 ^{cdef}	7 33 ^{def}	10 00 ^{gh}	14 00 ^{gh}	15 33 ^{g}	16 66 ^{h}	18 00 ^{ij}	315 42

(Contd)

In a column, values superscripted by a common letter do not differ significantly in DMRT (P=0 05)

Treatments	Number of banana leaves (Mean of three replications)							Per cent increase
	At the time of inoculation	Months after inoculation						
		1	2	3	4	5	6	
T_{18} – Bangrici	5 66 ^{ab}	8 33 ^{abc}	10 66 ^{efg}	14 66 ^{fg}	16 66 ^{f}	18 00 ^{g}	19 00 ^{hi}	235 27
T_{19} Pisang Nangka	5 33 ^{abc}	8 33 ^{abc}	10 66 ^{efg}	14 66 ^{fg}	16 66 ^{f}	18 33 ^{g}	19 33 ^{gh}	262 52
T_{20} – Popoulu	5 00 ^{abcd}	7 66 ^{cde}	10 66 ^{efg}	16 33 ^{cd}	18 33 ^{bcd}	19 66 ^{ef}	20 66 ^{ef}	313 34
T_{21} Pisang Madu	4 66 ^{bcde}	6 66 ^{fg}	9 00 ^{j}	12 66 ^{i}	14 33 ^{g}	15 33 ^{i}	16 33 ^{k}	249 97
T_{22} Pisang Ceylan	3 67 ^{ef}	7 00 ^{efg}	10 66 ^{efg}	16 33 ^{cd}	19 33 ^{b}	22 00 ^{bc}	24 33 ^{b}	563 57
T_{23} Pisang Jari Buaya	6 00 ^{a}	9 00 ^{a}	12 00 ^{bc}	18 00 ^{b}	21 00 ^{a}	23 00 ^{ab}	24 66 ^{ab}	311 12
T_{24} Pisang Buntal	4 66 ^{bcde}	7 66 ^{cde}	10 66 ^{efg}	16 00 ^{cde}	18 00 ^{cde}	19 66 ^{ef}	20 66 ^{ef}	342 83
T_{25} Robusta	5 00 ^{abcd}	7 00 ^{efg}	9 00 ^{ij}	13 00 ^{hi}	14 66 ^{g}	15 66 ^{hi}	16 66 ^{k}	233 34

In a column, values superscripted by a common letter do not differ significantly in DMRT (P=0 05)

4 1 2 Nematode population

Twenty five banana varieties were screened for the evaluation of the resistance/susceptibility response against *M incognita* Population of nematodes in soil and root, number of root knots formed due to the nematode infestation and root knot index were considered for rating the varieties as resistant or susceptible

4 1 2 1 Nematode population in soil

Nematode population in soil collected from all the banana varieties at the time of uprooting is presented in Table 6 Data showed significant variation among the different varieties The mean nematode population of soil ranged from 0 67 to 328 67 per 250 g soil The highest population was obtained from the variety Karpooravally Dwarf with 328 67 per 250 g soil followed by Robusta, Pisang Buntal and FHIA-18 with an average nematode population of 325 67, 324 00 and 306 67 per 250 g soil respectively These were statistically on par with each other The lowest population of nematodes was recorded from SH 3640 (0 67 /250 g soil) followed by SH–3436 6 and SH–3436 9 with an average population of 13 33 and 15 67 per 250 g soil, respectively Nematode population from rest of the varieties varied between 19 33 and 170 67 per 250 g soil

4 1 2 2 Nematode population in root

Statistical analysis of the data indicated that there was significant variation in the nematode population among different varieties (Table 6) Highest population was recorded from Robusta with an average of 336 00 per 20 g root followed by Pisang Buntal (302 33 / 20 g root) and Pisang Jari Buaya (242 67 / 20 g root) These were statistically on par with each other The lowest nematode population was recorded from SH-3640 with 4 33 per 20 g root followed by SH–3436 6 (4 33 / 20 g root) and SH-3436 9 (5 33 / 20 g root) Nematode population in all other varieties varied in between 6 67 and 164 67 per 20 g root

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4 1 2 3 Number of root knots

The number of knots in 20 g roots are presented in Table 6 The number of root knots among the different varieties varied between 3 67 (SH–3640) and 267 67 (Robusta) Pisang Buntal (256 00) was found to be statistically on par with Robusta followed by Pisang Ceylan (187 00) SH –3436 6 was found to be statistically on par with SH–3640 (6 00) All other varieties were reported to have root knots in between 11 67 and 146 00

4 1 2 4 Root knot index

Data regarding root knot index are presented in Table 6 Considering the root knot index the superior varieties were SH–3640 and SH–3436 6 with a root knot index of 2 This was followed by FHIA 1, FHIA-3, SH–3436 9, TMB × 5295-1, Udayam, Dudhsagar, Manjeri Nendran II, Big Ebanga and Pisang Nangka with an average root knot index of 3 The varieties *viz* TMP 2829, Mysore Ethan Sugandhi, Yangambi Km5, Bangrier, Popoulu and Pisang Madu scored root knot index of 4 whereas, the highest root knot index of 5 was recorded by Robusta, Pisang Buntal, Pisang Jari Buaya Pisang Ceylan, Karpooravally Dwarf FHIA 18 and FHIA-17

Based on root knot number and root knot index two hybrids, namely, SH 3640 and SH–3436 6 rated as resistant to *M incognita* (Plate 4), nine varieties, namely, FHIA 1, FHIA 3, SH–3436-9, TMB × 5295-1 Udayam, Dudhsagar, Manjeri Nendran II, Big Ebanga and Pisang Nangka as moderately resistant (Plate 5), seven varieties, namely, TMP 2829, Mysore Ethan, Sugandhi, Yangambi Km5, Bangrier, Popoulu and Pisang Madu as susceptible (Plate 6) and another seven varieties, namely, FHIA-17, FHIA 18, Karpooravally Dwarf, Pisang Ceylan, Pisang Jari Buaya, Pisang Buntal and Robusta as highly susceptible (Plate 7)

Table 6 Population of *M. incognita* at the time of uprooting and the reaction of banana varieties (Mean of three replications)

Treatments	Nematode population		Number of root knots	Root knot index	Reaction
	No./250 g soil	No./20 g root	No / 20 g root		
T_1 - FHIA -1	35 33 ^{fgh} (5 97)	23 00 ^{ijk} (4 80)	16 00 ^{hi} (4 04)	3	Moderately resistant
T_2 - FHIA -3	57 00 ^{def} (7 51)	32 33 ^{hijk} (5 61)	23 33 ^{gh} (4 93)	3	Moderately resistant
T_3 - FHIA -17	169 67 ^{b} (13 01)	113 33 ^{cde} (10 60)	123 00 ^{c} (11 10)	5	Highly susceptible
T_4 - FHIA -18	306 67 ^{a} (17 52)	73 33 ^{cfg} (8 57)	124 00 ^{c} (6 82)	5	Highly susceptible
T_5 - TMP 2829	71 00 ^{cde} (8 34)	51 00 ^{ghi} (6 98)	46 33 ^{e} (6 82)	4	Susceptible
T_6 SH – 3640	0 67 ^{j} (0 999)	4 33 ^{m} (1 94)	3 67 ^{k} (2 02)	2	Resistant
T_7 - SH –3436-6	13 33 (3 68)	5 33 ^{lm} (2 29)	6 00 ^{jk} (2 54)	2	Resistant
T_8 - SH –3436-9	15 67 ^{i} (3 99)	6 67 ^{lm} (2 39)	11 67 ^{ij} (3 46)	3	Moderately resistant

(Contd)

Values in paranthesis are SQRT transformed values

In a column, values superscripted by a common letter do not differ significantly in DMRT (P=0 05)

Treatments	Nematode population		Number of root knots	Root knot index	Reaction
	No./20 g root	No./ 20 g root	No / 20 g root		
T_9 - TMB × 5295-1	19 33 ^{hi} (4 44)	11 00 ^{klm} (3 35)	12 00 ^{ij} (3 52)	3	Moderately resistant
T_{10} – Udayam	58 33 ^{def} (7 58)	20 33 ^{jkl} (4 48)	15 33 ^{hi} (3 97)	3	Moderately resistant
T_{11} – Dudhsagar	36 67 ^{fgh} (6 06)	30 00 ^{ijk} (5 51)	15 67 ^{hi} (3 97)	3	Moderately resistant
T_{12} - Karpooravally Dwarf	328 67 ^{a} (18 07)	128 67 ^{cd} (11 24)	138 33 ^{c} (11 77)	5	Highly susceptible
T_{13} - Mysore Ethan	24 67 ^{ghi} (4 97)	24 00 ^{ijk} (4 94)	33 67 ^{efg} (5 84)	4	Susceptible
T_{14} – Sugandhi	36 00 ^{fgh} (6 02)	24 33 ^{ijk} (4 96)	41 67 ^{e} (6 48)	4	Susceptible
T_{15} - Manjeri Nendran II	68 33 ^{cde} (8 25)	46 33 ^{ghij} (6 81)	26 67 ^{g} (5 15)	3	Moderately resistant
T_{16} - Yangambi Km5	97 00 ^{c} (9 81)	65 33 ^{fgh} (7 99)	40 33 ^{ef} (6 38)	4	Susceptible
T_{17} - Big Ebanga	45 00 ^{efg} (6 73)	15 67 ^{klm} (3 94)	14 33 ^{i} (3 83)	3	Moderately resistant

(Contd)

Values in paranthesis are SQRT transformed values

In a column, values superscripted by a common letter do not differ significantly in DMRT (P=0 05)

Treatments	Nematode population		Number of root knots	Root knot index	Reaction
	No /20 g root	No./ 20 g root	No / 20 g root		
T_{18} – Bangrier	47 67 ^{defg} (6 92)	44 67 ^{ghij} (6 68)	41 00 ^{c} (6 43)	4	Susceptible
T_{19} - Pisang Nangka	152 33 ^{b} (12 34)	51 00 ^{fghi} (7 17)	28 33 ^{fg} (5 37)	3	Moderately resistant
T_{20} – Popoulu	142 00 ^{b} (11 91)	69 00 ^{efg} (8 33)	76 33 ^{d} (8 72)	4	Susceptible
T_{21} Pisang Madu	77 33 ^{cd} (8 79)	88 00 ^{def} (9 40)	84 00 ^{d} (9 18)	4	Susceptible
T_{22} - Pisang Ceylan	170 67 ^{b} (13 08)	164 67 ^{c} (12 78)	187 00 ^{b} (13 69)	5	Highly susceptible
T_{23} - Pisang Jari Buaya	149 33 ^{b} (12 20)	242 67 ^{b} (15 55)	146 00 ^{c} (12 10)	5	Highly susceptible
T_{24} - Pisang Buntal	324 00 ^{a} (17 99)	302 33 ^{b} (15 55)	256 00 ^{a} (16 00)	5	Highly susceptible
T_{25} – Robusta	325 67 ^{a} (18 00)	336 00 ^{ab} (18 26)	267 67 ^{a} (16 38)	5	Highly susceptible

Values in paranthesis are SQRT transformed values

In a column, values superscripted by a common letter do not differ significantly in DMRT (P=0 05)

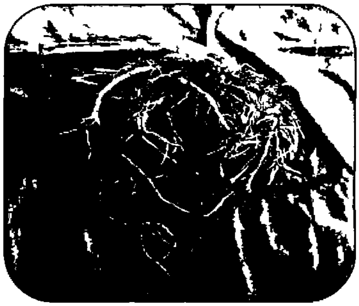
Plate 4. Banana varieties/hybrids resistant to *Meloidogyne incognita*

T_6 SH – 3640

T_7 SH 3436 6

Plate 5. Banana varieties/hybrids moderately resistant to *Meloidogyne incognita*

T_1 FHIA 1



T FHIA 3

T TMB x 5295 1

T SH-3436 9

Contd

T_1 Dudhsagar

T Manjeri Nendran II

T_{17} Big Ebanga

T_1 Udhayam

T_1 Pisang Nangka

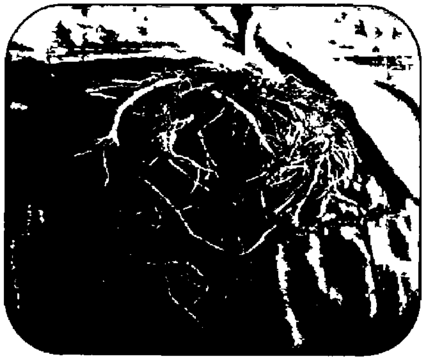
Contd

Plate 6. Banana varieties/hybrids susceptible to *Meloidogyne incognita*

T TMP 2829

T Mysore Ethan

T_{11} Sugandhi

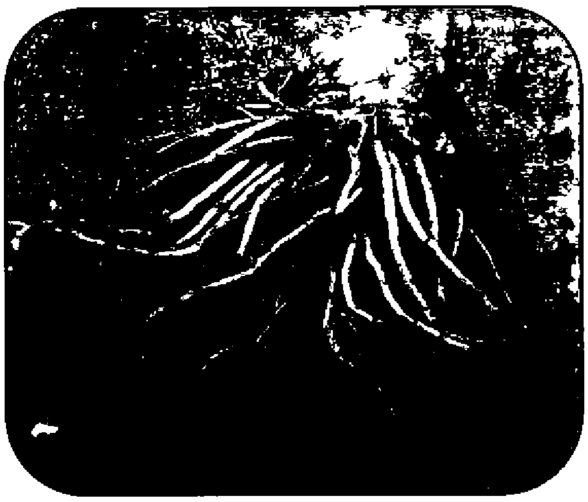


T_{1} Yangambi Km5

Contd

T_8 – Bangrier

T – Popoulu



T_1 Pisang Madu

Plate 7. Banana varieties/hybrids highly susceptible to *Meloidogyne incognita*

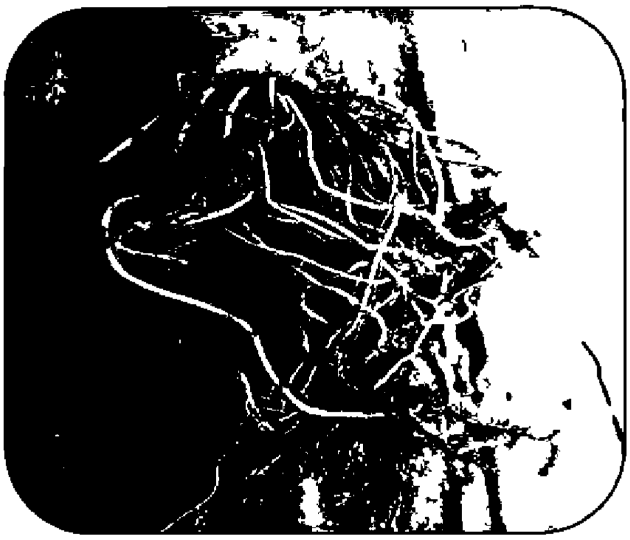
T_1 FHIA 1

T FHIA 3

T – Karpoorvally Dwarf

T Pisang Ceylan

Contd



T – Pisang Jari Buaya

T_4 – Pisang Buntal

T_5 – Robusta

4 2 BIOCHEMICAL BASIS OF RESISTANCE

Biochemical basis of resistance of different banana varieties to root knot nematode, *M incognita* were ascertained by estimating total phenol content, activities of enzymes like polyphenol oxidase, peroxidase and phenylalanine ammonia lyase in the banana roots at three months after inoculation The results are presented in Table 7

4 2 1 Total phenol content

Total phenol content varied significantly among the banana varieties evaluated The mean total phenol content ranged from 91 70 to 372 07 mg g^{1} in different varieties The resistant hybrids, namely, SH–3436 6 and SH–3640 recorded higher total phenol of 372 67 mg g^{1} and 319 37 mg g^{1}, respectively Next highest total phenol content was recorded from moderately resistant variety Big Ebanga with 275 10 mg g^{1} which in turn was on par with susceptible variety Bangrier (269 83 mg g^{1}) and moderately resistant variety Dudhsagar (255 07 mg g^{1}) The lowest total phenol content was recorded from highly susceptible variety Pisang Buntal with 91 70 mg g^{1} followed by Popoulu (susceptible) with 106 72 mg g^{1} and Kaipooravally Dwarf (highly susceptible) with 110 14 mg g^{1} and was significantly different from each other Total phenol content recorded from all other varieties ranged from 140 71 mg g^{1} to 243 48 mg g^{1}

4 2 2 Polyphenol oxidase activity

The polyphenol oxidase activity of banana roots of different varieties are given in Table 7 The resistant hybrid SH – 3640 recorded the highest activity of 0 12 EU g^{1} followed by moderately resistant variety Big Ebanga with 0 11 EU g^{1} SH–3436-9 (resistant) recorded next highest activity of 0 09 EU g^{1} and was significantly different from all other varieties The lowest activity was recorded from highly susceptible varieties *viz* Robusta (0 01 EU g^{1}), Pisang Buntal (0 01 EU g^{1}), Pisang

Ceylan (0 02 EU g^{1}) and Pisang Jari Buaya (0 02 EU g^{1}) which are statistically on par with each other The polyphenol oxidase activity recorded from all other varieties varied between 0 03 EU g-1 and 0 08 EU g^{1}

4 2 3 Peroxidase activity

Peroxidase activity estimated from banana roots are given in Table 7 Results showed that the values ranged from 0 17 EU g^{1} to 0 48 EU g^{1} The highest peroxidase activity was recorded from the resistant hybrid SH-3640 and susceptible variety Mysore Ethan with 0 48 EU g^{1} The lowest was recorded from the highly susceptible varieties Pisang Buntal and Robusta with 0 17 EU g^{1} All other varieties recorded an enzyme activity in between 0 20 EU g^{1} and 0 46 EU g^{1} The general observations showed that the resistance of banana varieties increases with increase in the activity of enzymes

4 2 4 Phenylalanine ammonia lyase activity

The highest activity of phenylalanine ammonia lyase was recorded from moderately resistant variety Big Ebanga with 2 66 µmol g^{1} It was followed by FHIA -18 (highly susceptible), TMB × 5295 1 (moderately resistant), SH –3436-9 (moderately resistant), SH–3640 (resistant), FHIA-1 (moderately resistant), Bangrier (susceptible), Pisang Madu (susceptible), Udayam (moderately resistant), Dudhsagar (moderately resistant), Sugandhi (susceptible) and Mysore Ethan (susceptible) with a mean enzyme activity of 2 58, 2 53, 2 51, 2 48, 2 46, 2 44, 2 43, 2 35, 2 32, 2 25 and 2 25 µmol g^{1} respectively and were statistically on par with each other The lowest enzyme activity was recorded from highly susceptible varieties Pisang Buntal with 1 048 µmol g^{1} followed by Robusta (1 23 µmol g^{1}) All other varieties recorded an average PAL activity in between1 42 and 2 21 µmol g^{1}

Table 7. Biochemical parameters in different banana varieties/hybrids at three months after inoculation

Treatments	Biochemical parameters (Mean of three replications)			
	Total phenol (mg g^{-1})	Polyphenol oxidase activity (EU g^{-1})	Peroxidase activity (EU g^{-1})	Phenylalanine ammonia lyase activity (µmol g^{-1})
T_1 FHIA -1	243 45 ^{cd} (15 62)	0 05 ^{ghi} (0 22)	0 40 ^{b} (0 95)	2 46 ^{abcd} (1 72)
T_2 - FHIA -3	228 72 ^{cd} (15 13)	0 06 ^{fg} (0 25)	0 41 ^{b} (0 95)	1 67 ^{fg} (1 47)
T_3 FHIA 17	164 95 ^{c} (12 86)	0 04 ^{i} (0 20)	0 21 ^{fg} (0 84)	2 07 ^{de} (1 75)
T_4 - FHIA -18	159 16 ^{c} (12 53)	0 06 ^{fgh} (0 24)	0 20 ^{fgh} (0 84)	2 58 ^{ab} (1 73)
T_5 TMP 2829	166 54 ^{c} (12 90)	0 06 ^{fgh} (0 24)	0 46 ^{a} (0 98)	2 21 ^{bcde} (1 65)
T_6 - SH – 3640	319 37 ^{ab} (17 88)	0 12 ^{a} (0 34)	0 48 ^{a} (0 99)	2 48 ^{abcd} (1 73)
T_7 - SH –3436 6	372 07 ^{a} (19 30)	0 11 ^{ab} (0 33)	0 41 ^{b} (0 95)	2 19 ^{bcde} (1 64)
T_8 - SH –3436-9	233 99 ^{cd} (15 30)	0 09 ^{bc} (0 31)	0 38 ^{bc} (0 94)	2 51 ^{abcd} (1 73)

(Contd)

Values in paranthesis are SQRT transformed values

In a column, values superscripted by a common letter do not differ significantly in DMRT (P=0 01)

Treatments	Biochemical parameters (Mean of three replications)			
	Total phenol (mg g^{-1})	Polyphenol oxidase activity (EU g^{-1})	Peroxidase activity (EU g^{-1})	Phenylalanine ammonia lyase activity (μmol g^{-1})
T_9 - TMB × 5295-1	151 25^{ef} (12 30)	0 06^{fg} (0 25)	0 33de (0 91)	2 53^{abc} (1 74)
T_{10} – Udayam	222 92^{cd} (14 94)	0 08^{d} (0 28)	0 31^{e} (0 90)	2 35^{abcd} (1 69)
T_{11} – Dudhsagar	255 07^{bc} (15 99)	0 08^{cd} (0 29)	0 41^{b} (0 95)	2 32^{abcd} (1 68)
T_{12} - Karpooravally dwarf	110 14^{fgh} (10 51)	0 03^{j} (0 17)	0 38^{bc} (0 94)	1 42^{gh} (1 39)
T_{13} - Mysore Ethan	140 71^{efg} (11 88)	0 06^{ef} (0 25)	0 48^{a} (0 99)	2 25^{abcde} (1 66)
T_{14} – Sugandhi	233 46^{cd} (15 20)	0 05^{hi} (0 22)	0 35^{cd} (0 92)	2 53^{abcde} (1 66)
T_{15} - Manjeri Nendran II	236 10^{cd} (15 38)	0 06^{fg} (0 24)	0 24^{f} (0 86)	2 09^{cde} (1 61)
T_{16} Yangambi Km5	226 09^{cd} (15 05)	0 05^{ghi} (0 22)	0 37^{bc} (0 93)	2 06de (1 60)
T_{17} - Big Ebanga	275 10^{bc} (16 60)	0 11^{ab} (0 33)	0 33^{cde} (0 91)	2 66^{a} (1 78)

(Contd)

Values in paranthesis are SQRT transformed values

In a column, values superscripted by a common letter do not differ significantly in DMRT (P=0 01)

Treatments	Biochemical parameters (Mean of three replications)			
	Total phenol (mg g^{-1})	Polyphenol oxidase activity (EU g^{-1})	Peroxidase activity (EU g^{-1})	Phenylalanine ammonia lyase activity (µmol g^{-1})
T_{18} – Bangrier	269 83 ^{bc} (16 39)	0 06^{fgh} (0 23)	0 32 ^{de} (0 91)	2 44 ^{abcd} (1 72)
T_{19} Pisang Nangka	236 63 ^{cd} (10 25)	0 09^{d} (0 28)	0 23 ^{f} (0 85)	2 14 ^{bcde} (1 62)
T_{20} – Popoulu	106 72 ^{gh} (10 25)	0 06^{ef} (0 25)	0 21 ^{f} (0 84)	1 89 ^{ef} (1 55)
T_{21} - Pisang Madu	191 83 ^{de} (13 79)	0 08de (0 27)	0 34 ^{cde} (0 92)	2 43 ^{abcd} (1 71)
T_{22} Pisang Ceylan	140 71 ^{efg} (11 85)	0 02^{k} (0 13)	0 33 ^{de} (0 91)	2 10 ^{cde} (1 61)
T_{23} - Pisang Jari Buaya	158 63 ^{e} (12 61)	0 02^{k} (0 13)	0 22 ^{f} (0 85)	1 50 ^{gh} (1 41)
T_{24} - Pisang Buntal	91 70 ^{h} (9 60)	0 01^{k} (0 12)	0 17 ^{h} (0 82)	1 05^{i} (1 24)
T_{25} - Robusta	170 22 ^{e} (12 99)	0 01^{k} (0 14)	0 17 ^{gh} (0 82)	1 23 ^{hi} (1 31)

Values in paranthesis are SQRT transformed values

In a column, values superscripted by a common letter do not differ significantly in DMRT (P=0 01)

4 3 CORRELATION OF BIOCHEMICAL PARAMETERS WITH ROOT KNOT NEMATODE INFESTATION AND POPULATION

Statistical analysis was carried out to ascertain the correlation between biochemical parameters at the time of uprooting and nematode population in root and soil The results are presented in Table 8

4 3 1 Total phenol content

Total phenol content exhibited negative and significant correlation at 0 01 per cent level with number of root knots (0 65), root knot index (-0 79), nematode population in root (-0 57) as well as in soil (0 65)

4 3 2 Polyphenol oxidase activity

Polyphenol oxidase activity showed negative correlation with number of root knots (0 80), root knot index (0 84), nematode population in root (-0 79) as well as in soil (0 68) These were found significant at 0 01 per cent level

4 3 3 Peroxidase activity

Peroxidase activity had significant and negative correlation at 0 01 per cent level with number of root knots (-0 63), root knot index (-0 53), nematode population in root (-0 64) as well as in soil (-0 67)

4 3 3 Phenylalanine ammonia lyase activity

The activity of phenylalanine ammonia lyase showed significant and negative correlation with number of root knots (0 61), root knot index (0 45), nematode population in root (-0 68) as well as in soil (-0 58) These were significant at 0 01 per cent level

Table 8. Correlation of biochemical parameters with population of root knot nematode

	Root knot number	Root knot index	Nematode population in root	Nematode population in soil	Total phenol	Polyphenol oxidase	Peroxidase
Root knot index	0 83**						
Nematode population in root	0 96**	0 74**					
Nematode population in soil	0 87**	0 78**	0 79**				
Total phenol	-0 65**	-0 79**	0 57**	0 65**			
Polyphenol oxidase	-0 80**	0 84**	0 79**	0 68**	0 75**		
Peroxidase	-0 63**	-0 53**	-0 64**	0 67**	0 43*	0 50*	
Phenylalanine ammonia lyase	-0 61**	-0 45**	0 68**	0 58**	0 47*	0 65**	0 33^{ns}

** Correlation is significant at 0 01 level (2 tailed)

* Correlation is significant at 0 05 level (2-tailed)

Discussion

5. DISCUSSION

Root knot nematodes are one of the important groups of plant parasitic nematodes in banana requiring concerned efforts for management Management of these nematode mainly relies on the repeated use of chemical nematicides which has adverse effect on environment Breeding of bananas hybrids with nematode resistance is an alternate strategy for controlling this pest simultaneously ensuring environmental safety Limited information is available on the existence of sources of resistance and tolerance to root knot nematode, *M incognita* in banana

In this context, an attempt was made to screen different banana varieties for the source of resistance against *M incognita*

Twenty five banana varieties from the germplasm collection of Banana Research Station, Kannara comprising of nine exotic hybrids, six Indian varieties, nine exotic varieties and a highly susceptible check (Robusta) were screened for their response to *M incognita* Nematodes were inoculated @ one second stage juvenile per gram of soil at forty five days after planting Monthly observations were taken on the biometric characters of banana *viz* plant height, pseudostem girth and number of leaves from the time of inoculation till uprooting The biochemical parameters like total phenol content, peroxidase (PO), polyphenol oxidase (PPO) and phenylalanine ammonia lyase (PAL) activity were estimated at three months after inoculation using accepted standard procedure Six months after inoculation all the plants were uprooted and the nematode damage in the root system of all the varieties were studied The results of the study are discussed in this chapter

5 1 SCREENING OF BANANA VARIETIES / HYBRIDS AGAINST ROOT KNOT NEMATODE, *M incognita*

5 1 1 Biometric characters of banana varieties

The results presented in Table 3, 4 and 5 indicated that all the varieties showed an increasing trend in terms of height, girth and number of leaves and there was significant variation existed among the varieties

The mean height of the plants at the time of inoculation and at the time of uprooting ranged from 24 55 to 48 76 cm and 52 07 to 74 93 cm, respectively The highly susceptible variety Karpooravally Dwarf recorded highest increase of 155 71 per cent followed by susceptible variety Popoulu and moderately resistant hybrid FHIA-3 with 144 93 and 142 14 per cent increase, respectively The lowest increase in plant height was observed in susceptible variety Yangambi Km5 (30 85 %) followed by highly susceptible varieties Pisang Buntal (34 58 %) and Robusta (35 24 %) The increase in height of all the other varieties ranged from 40 74 to 141 37 per cent

Highest increase in pseudostem girth of 96 30 per cent was observed in moderately resistant hybrids FHIA-1 and FHIA-3 followed by susceptible variety Popoulu and moderately resistant variety Udayam with 81 11 and 66 67 per cent respectively The lowest increase in pseudostem girth was observed in highly susceptible variety Robusta with 14 29 per cent followed by resistant hybrid SH-3640 with 18 19 per cent Increase in pseudostem girth of rest of the varieties ranged from 22 93 to 65 92 per cent

The highly susceptible variety Pisang Ceylan scored highest increase of 563 57 per cent and susceptible check Robusta scored lowest increase of 233 34 per cent in leaf production within six months Increase in total number of leaves of all the other varieties recorded in between 235 27 and 541 68 per cent

The results revealed that variation in height, girth and number of leaves among the different varieties were not due to the infection of nematodes The increase in height, girth and number of leaves can be considered as a plant attribute

5 1 2 Nematode population

5 1 2 1 Number of root knots

In the present study the number of root knots from 20 g root of different varieties varied between 3 67 and 267 67 (Table 6) Root knots are the main visible symptoms of *M incognita* attack and were found in primary and secondary roots of banana Among the 25 varieties/hybrids tested the resistant hybrid SH-3640 recorded the lowest root knot number of 3 67 followed by SH–3436-6 (resistant) with 6 00 whereas, the highly susceptible varieties Robusta and Pisang Buntal recorded highest root knot number of 267 67 and 256 00 per 20 g root All other varieties were reported to have root knots in between 11 67 and 146 00 per 20 g root

These root knots were formed by the penetration and establishment of permanent feeding site by the second stage juveniles of root knot nematodes The feeding sites are formed in the differentiation zone of the root and thus cause nuclear division without cytokinesis in host cells This process gives rise to large, multinucleate cells, termed giant cells The plant cells around the feeding site divide and swell, causing the formation of galls or root knots in the primary and secondary roots (Williamson and Hussey, 1996)

The susceptible plants support the formation of feeding sites and reproduction of root knot nematode But the resistant plants form necrotic areas near the feeding site due to cell hypersensitivity and causes detrimental effects to the development and reproduction of nematodes (Seo *et al* , 2014)

In the present study it was observed that the population of nematodes from root and soil were in direct relation with root knot number, root knot index and susceptibility of different banana varieties/hybrids Similar observations were also reported by Das *et al* (2014a) in banana hybrids

Thus the difference in susceptibility/resistance of banana varieties to *M incognita* could be related to the variation in number of root knots Hence the varieties/hybrids with low root knot number were considered to be resistant compared to other varieties/ hybrids with high root knot number

5 1 2 2 Root knot index

Root knot index was calculated on the basis of the classification given by Gitanjalidevi *et al* (2014) on 1- 5 scale Data regarding root knot index are presented in Table 6 Based on the root knot number and root knot index the varieties were classified as resistant, moderately resistant, susceptible and highly susceptible

Classification of resistance based on root knot number

Sl No	Root knot index	No of galls/ plant	Reaction
1	1	No galls	Highly resistant
2	2	1-10 galls	Resistant
3	3	11-30 galls	Moderately resistant
4	4	31 100 galls	Susceptible
5	5	101 and above	Highly susceptible

In the present study none of the varieties tested were found to be highly resistant with root knot index of 1 whereas, two hybrids, namely, SH–3640 and SH–3436 6 with a root knot index of 2 were observed as resistant This was followed by moderately resistant varieties *viz* FHIA 1, FHIA 3, SH–3436 9, TMB × 5295 1 Udayam, Dudhsagar, Manjeri Nendran II, Big Ebanga and Pisang Nangka with an average root knot index of 3 The varieties *viz*, TMP 2829, Mysore Ethan, Sugandhi, Yangambi Km5, Bangrier, Popoulu and Pisang Madu scored root knot index of 4 were considered as susceptible The highest root knot index of 5 was recorded from Robusta, Pisang Buntal, Pisang Jari Buaya, Pisang Ceylan, Karpooravally Dwarf, FHIA -18 and FHIA -17 and were rated as highly susceptible

The susceptibility of FHIA-17, SH–3436-9, TMB × 5295-1, Pisang Ceylan and the moderate resistance of SH–3640 towards plant parasitic nematodes was reported by Cruz *et al* (2008) FHIA-1 was recorded as susceptible to *M incognita* (Moens *et al* 2006) and *M javanica* (Gaidashova, 2008) whereas it was reported to be less susceptible to *M incognita* in Vietnam Araya and De Waele (2011) reported that Yangambi Km5, FHIA-18, Pisang Jari Bauya were susceptible to *Meloidogyne* spp

5 1 2 Nematode population in root

Statistical analysis of the data indicated that there was significant variation in the nematode population of different varieties (Table 6) Lowest population was recorded from the resistant hybrids like SH–3640 with 4 33 per 20 g root followed by SH–3436 6 and (4 33/20 g root) The highest population was recorded from Robusta with an average of 336 00 followed by Pisang Buntal (302 33 per 20 g root) and Pisang Jari Buaya (242 67 per 20 g root) These varieties were found to be highly susceptible with respect to root knot index and root knot number All other varieties recorded a mean root population of 5 33 and 164 67 per 20 g root

From the results, it was observed that the population of nematodes was inversely proportional to the resistance reaction of banana varieties to root knot nematode Aung *et al* (1990) opined that the resistant varieties negatively affect the reproduction of nematodes in cowpea Many phenolic compounds were reported to have variation in suppressing the egg hatching of *M incognita* (Mahajan *et al*, 1992) and in the present study the total phenol contents were observed to be higher in resistant varieties

5 1 1 Nematode population in soil

Nematode population in soil collected from all the banana varieties at the time of uprooting is presented in Table 6 Data showed significant variation among the different varieties The mean nematode population of soil ranged from 0 67 to 328 67 per 250 g soil The lowest population of nematodes were recorded from SH–3640 (resistant) with 0 67 per 250 g soil followed by SH–3436-6 (resistant) and SH–3436 9 (moderately resistant) with an average population of 13 33 and 15 67 per 250 g soil, respectively These hybrids were also found to be resistant as per the root knot index rating The highest population was obtained from the variety Karpooravally Dwarf with 328 67 per 250 g soil followed by Robusta, Pisang Buntal and FHIA-18 with an average nematode population of 325 67, 324 00 and 306 67 per 250 g soil, respectively These were statistically on par with each other and were rated as highly susceptible according to root knot index Nematode population from rest of the varieties recorded between 19 33 and 170 67 per 250 g soil

The soil population of *M incognita* mainly comes from the eggs hatched from the egg masses near the periphery of roots It is obvious that the intensity of root knots and the chance of finding egg masses at the root periphery are directly proportional Since the resistant varieties had low root knot number than the susceptible varieties the population of nematodes in soil also showed similar trend

Dochez *et al* (2009) also reported the lowest population of *Meloidogyne* spp from SH-3640 in a field screening conducted against nematode complex including *Meloidogyne* spp in addition with other nematodes, *Radopholus similis Helicotylenchus multicinctus, H dihystera* and *Hoplolaimus pararobustus* SH-3640 showed low damage (as measured by their densities and root damage) due to nematodes and did not reduce significantly their plant height SH-3640 was rated as the solely resistant cultivar among those tested in this experiment Jesus and Wilken (2010) recorded less number of *M incognita* Race 2 and *M javanica* from SH-3640 but it was rated as susceptible

5 2 BIOCHEMICAL BASIS OF RESISTANCE

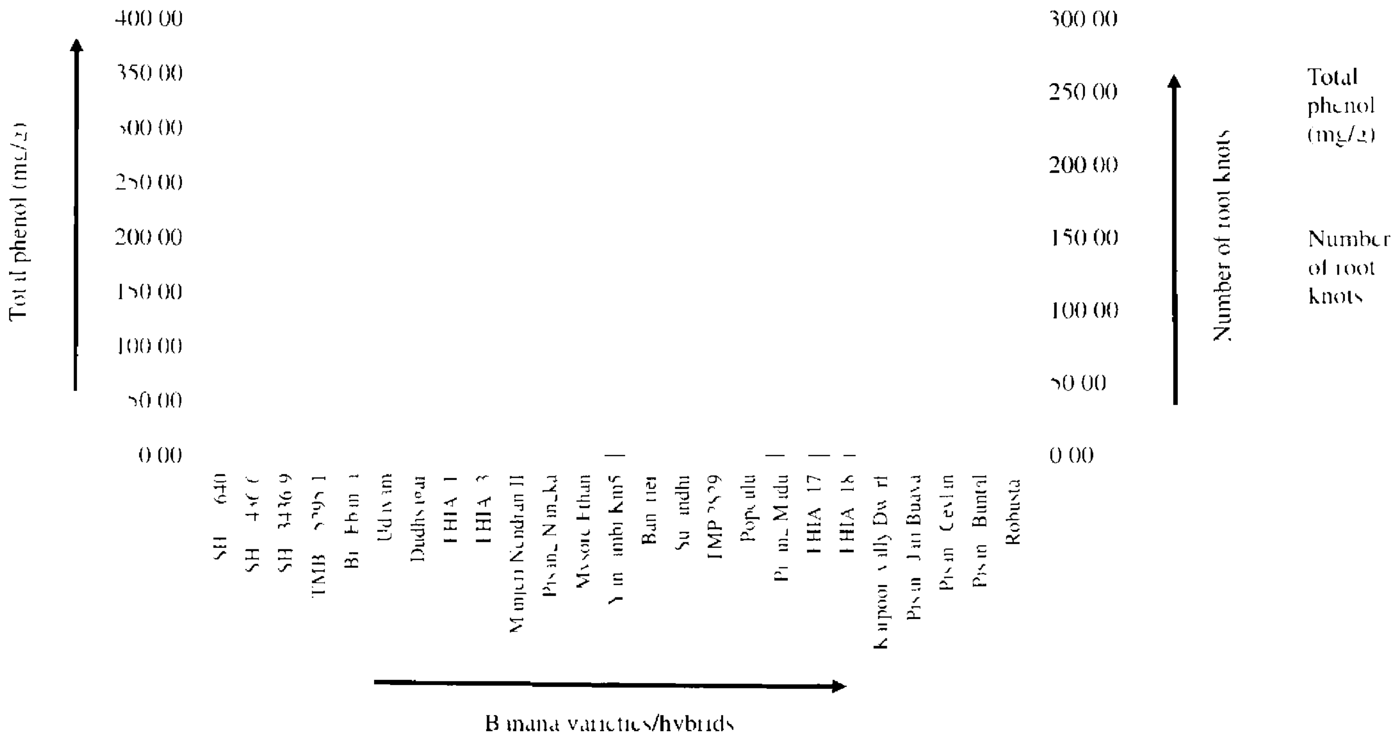
Analysis of biochemical parameters such as total phenol, peroxidase (PO), polyphenol oxidase (PPO), phenylalanine ammonia lyase (PAL) activity in banana roots infested with *M incognita* implicated the physiological response of the varieties against root knot nematode The relationship between the biochemical parameters and the level of root knot infestation brought out in the study (Table 7) are discussed below

5 2 1 Total phenol

The role of phenolic compounds in the defense mechanism of the plants and consequently their accumulation in the cells damaged by nematode feeding has been reported by Acedo and Rohde (1971), Valette *et al* (1998) This accumulation might be due to the excess production of hydrogen peroxide by increased respiration (Farkas and Kirlay, 1996) or due to the activation of hexose monophosphate (HMP) shunt pathway, acetate pathway and release of bound phenols by hydrolytic enzymes (Goodman *et al*, 1967)

The higher content of total phenol was recorded by resistant and moderately resistant varieties than the susceptible and highly susceptible varieties (Fig 1) The resistant hybrids SH–3640 and SH–3436-6 scored the highest total phenol content of 372 07 mg g^{1} followed by SH–3640 with 319 37 mg g^{1} which was statistically on par with SH–3436 6 The lowest total phenol content was recorded from Pisang Buntal (highly susceptible) with 91 70 mg g^{1} followed by Popoulu (Susceptible) with 106 72 mg g^{1}

Fig 1. Influence of phenol content on number of root knots of different banana varieties/hybrids



The results thus obtained were in agreement with the findings of Krishnamoorthy and Kumar (2004), Damodaran *et al* (2007), Vaganan *et al* 2014 and Das *et al* 2014a They also reported higher phenol content in nematode resistant banana plants than susceptible ones

The correlation analysis showed a significant negative correlation between total phenol and root knot number (-0 65), root knot index (-0 79), root population (0 57) and soil population (-0 65) of root knot nematode

Gibel (1982) reported a distinct correlation between the degree of plant resistance and phenolics present in the plant tissues Increase in the concentration of free phenols following infestation by *M incognita* was reported earlier by Ganguly and Dasgupta (1984) The increase in phenols was reported to help in the formation of hypersensitive reaction towards the nematode infection (Shukla and Chakraborty 1988, Mazzafera *et al* , 1989) The early accumulation of phenolic compound at the infection site was reported as a result of the rapid hypersensitive death of cells (Fenandez and Heath, 1989)

5 2 2 Enzymatic activity

Enzymatic activity was reported as one of the important tools to confirm resistance to nematodes The infection of host by pathogens were reported to induce specific genes which resulted in the production of mRNA's that permit synthesis of similar number of specific proteins (Seenivasan and Murugan, 2011) Many of these proteins were recorded namely, phenylalanine ammonia lyase, polyphenol oxidase, peroxidase and β-1-3 glucanase (Seenivasan, 2011) These were involved in the synthesis of low molecular weight substance such as phytoalexins, phenols and lignin which are inhibitory to the invading pathogens Thus, the overall analysis of these enzymes in banana varieties indicated the role of these enzymes in conferring resistance to nematodes

5 2 2 1 Polyphenol oxidase activity

The PPO oxidizes the phenols to highly toxic quinones and hence is considered to play an important role in disease resistance, particularly those affecting the tissue (Abbattista and Matta, 1975)

Statistical analysis of the data regarding the polyphenol oxidase activity of banana roots is given in Table 7 and Fig 2 The resistant hybrid SH–3640 recorded the highest activity of 0 12 EU g^{1} followed by Big Ebanga (moderately resistant) and SH –3436 6 (resistant) with 0 11 EU g^{1} SH –3436-9 recorded next highest activity of 0 09 EU g^{1} and was significantly different from all other varieties The lowest activity was recorded from the highly susceptible varieties *viz* Robusta (0 01 EU g^{1}), Pisang Buntal (0 01 EU g^{1}), Pisang Ceylan (0 02 EU g^{1}) and Pisang Jari Buaya (0 02 EU g^{1}) which were statistically on par with each other The Polyphenol oxidase activity recorded from all other varieties varied in between 0 03 and 0 08 EU g^{1}

The enzymatic activity showed negative correlation with root knot number (0 80), root knot index (-0 84), nematode population in root (-0 79) as well as in soil (0 68) It was observed to be significant at 0 01 per cent level

High polyphenol oxidase activity was observed to be associated with nematode resistance (Das *et al* 2011 and 2014a) The increase in the polyphenol oxidase activity in the diseased tissues was reported to couple with the increase in phenolic concentration (Ahuja and Ahuja, 1980)

5 2 2 2 Peroxidase activity

Among the various enzymes, peroxidase was considered as one of the important defense related enzymes due to its role in catalyzing the condensation of phenolic compounds into lignin as well as synthesis of other trapezoids involved in phytoalexin production

Fig 2 Influence of polyphenol oxidase (PPO) on number of root knots of different banana varieties/hybrids

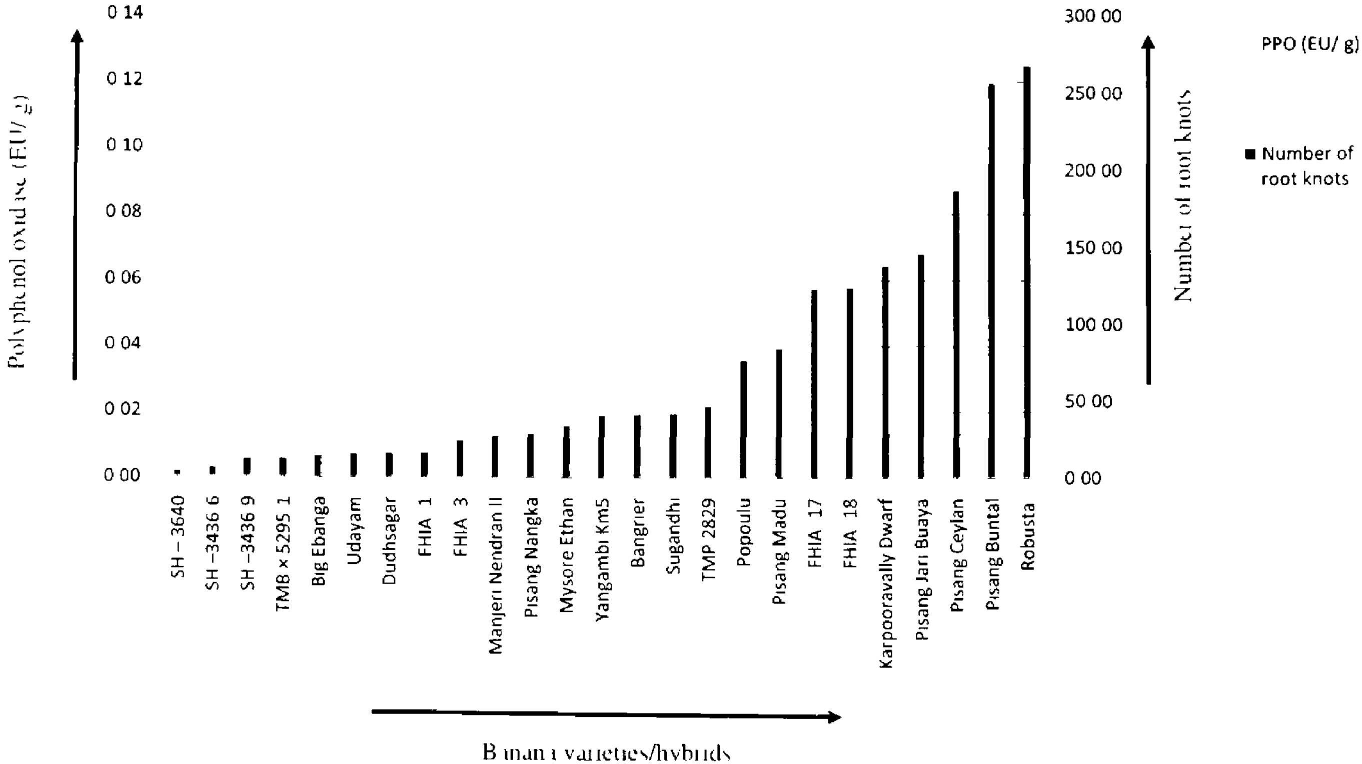
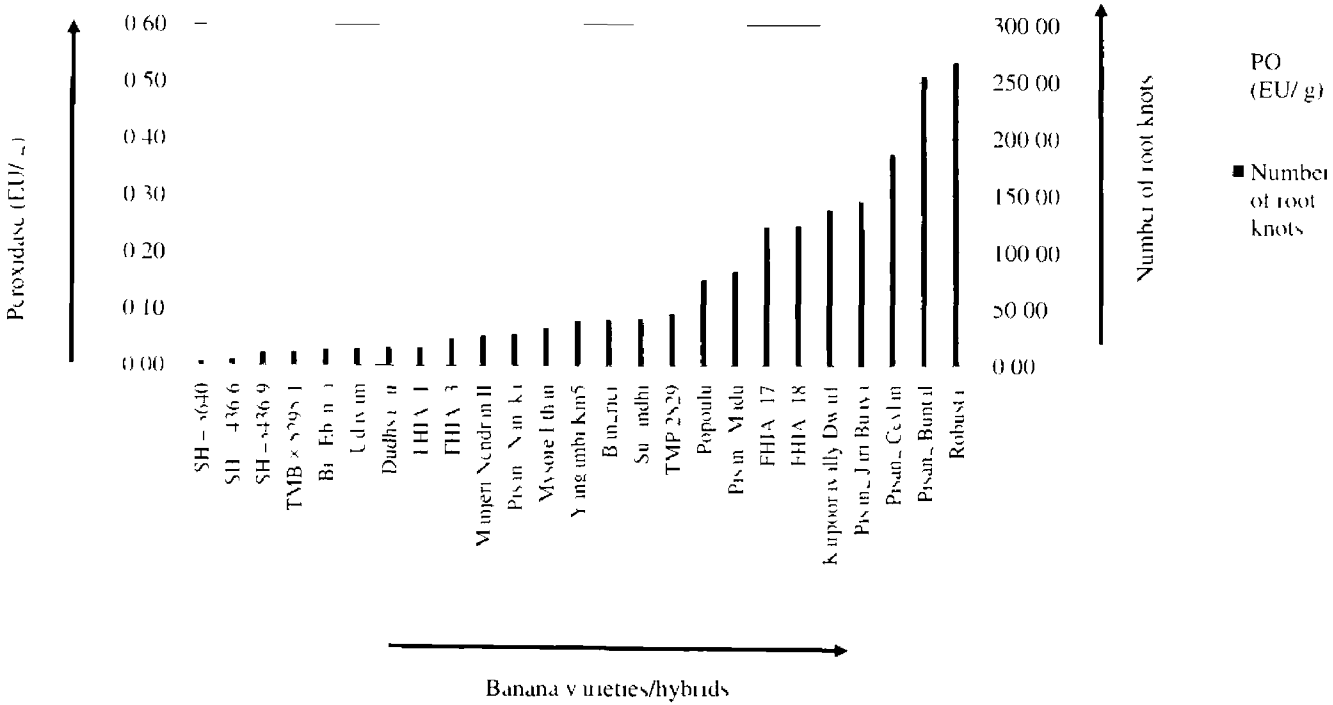


Fig 3 Influence of peroxidase (PO) on number of root knots of different banana varieties/hybrids



Peroxidase activity estimated from banana roots are given in Table 7 and Fig 3 All the banana varieties showed high level of peroxidase activity However, maximum enzyme activity was recorded in resistant and susceptible varieties like SH - 3640 (0 48 EU g^{1}), Mysore Ethan (0 48 EU g^{1}) and TMP 2829 (0 46 EU g^{1}) than highly susceptible varieties like Pisang Buntal (0 17 EU g^{1}) and Robusta (0 17 EU g^{1})

Peroxidase activity had significant and negative correlation with root knot number (0 63), root knot index (-0 53), nematode population in root (-0 64) as well as in soil (0 67)

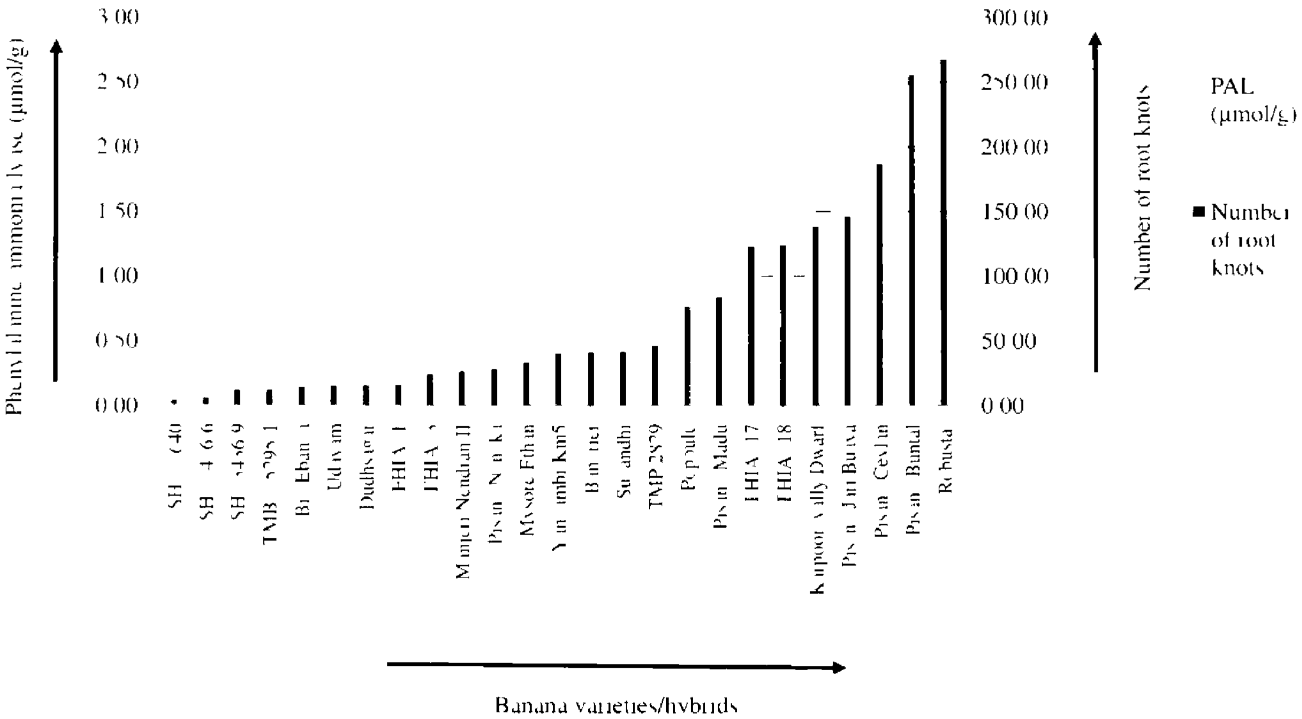
The results were in agreement with several workers who reported enhanced peroxidase activity associated with plants resistant to nematodes (Valette *et al* 1998, Fogain and Gowen, 1996) However, some varieties like Mysore Ethan showed high peroxidase activity even though it was susceptible to *M incognita* This might be due to the influence of internal and external factors due to nematode or plant

5 2 2 3 Phenylalanine ammonia lyase activity

Phenylalanine ammonia lyase was the first and the key enzyme that controls the phenylpropanoid biosynthetic pathway through which phenolic compounds of lignin, flavanoids and hydroxycinnamyl conjugates are synthesized PAL activity was an extremely sensitive indicator of stress conditions including pathogen infection as basically PAL is a stress related enzyme (Ascensao and Dubery, 2000)

The highest activity of PAL was recorded from moderately resistant variety Big Ebanga with 2 66 µmol g^{1} and the lowest was recorded from highly susceptible varieties namely, Pisang Buntal with 1 048 µmol g^{1} followed by Robusta (1 23 µmol g^{1}) (Fig 4) Eventhough the enzyme activity recorded much variation among the resistant and susceptible cultivars, correlation analysis showed significant and

Fig 4. Influence of phenylalanine ammonia lyase (PAL) on number of root knots of different banana varieties/hybrids



negative correlation with root knot number (0 61), root knot index (-0 45), nematode population in root (-0 68) as well as in soil (-0 58)

These results were in corroboration with the findings of Vaganan *et al* (2014) who reported higher activity of PAL coupled with high accumulation of phenolics in resistant cultivars which constitute a part of their resistant mechanism against nematodes

Increased activity of PAL in highly tolerant banana varieties and decreased enzyme activity in highly susceptible varieties were also reported by Krishnamoorthy *et al* (2005) and Das *et al* (2014a)

To sum up the findings, the present study revealed that considerable variation exists among the banana varieties in terms of resistance to *M incognita* The varieties SH–3640 (AAAB) and SH–3436-6 (AAAA) were found to be resistant FHIA 1(AAB), FHIA-3 (AABB), SH–3436-9 (AAAA), TMB × 5295-1 (AAAB), Udayam (ABB), Dudhsagar (AAB), Manjeri Nendran II (AAB), Big Ebanga (AAB) and Pisang Nangka (AAB) were moderately resistant, TMP 2829 (AB), Mysore Ethan (AAB), Sugandhi (AAB), Yangambi Km5 (AAA), Bangrier (ABB), Popoulu (AAB) and Pisang Madu (AA) were susceptible and FHIA -17 (AAAA), FHIA -18 (AAAB), Karpooravally Dwarf (ABB), Pisang Ceylan (AAB) Pisang Jari Buaya (AA), Pisang Buntal (AA) and Robusta (AAA) were highly susceptible Notable differences were also observed in the biometric characters of these varieties

From the findings it was evident that biochemical changes observed after the infestation of *M incognita* plays a key role in nematode resistance in *Musa* spp Biochemical parameters like total phenol content and activities of enzyme like polyphenol oxidase, peroxidase, and phenylalanine ammonia lyase were found to be increased in resistant varieties and could be used for screening the varieties against *M incognita* Such an information could be used in the selection of parents in further breeding programmes The possibility of using these induced biochemical changes in evolving new management strategy could not be ruled out

Summary

6. SUMMARY

The present study entitled 'Response of selected banana varieties to root knot nematode *Meloidogyne incognita* (Kofoid and White)' was carried out in the Department of Agricultural Entomology, College of Horticulture, Vellanikkara and Banana Research Station, Kannara during 2014 2015 Twenty five banana varieties from the germplasm collection of Banana Research station, Kannara comprising of nine exotic hybrids, six Indian varieties, nine exotic varieties and a highly susceptible check (Robusta) were screened for their response to *M incognita* The objectives of the study were to screen the selected banana varieties against root knot nematode, *Meloidogyne incognita* and to elucidate the biochemical bases of resistance

The effect of *M incognita* on the biometric characters of banana *viz*, plant height, pseudostem girth and number of leaves were observed at monthly intervals The biochemical characters like total phenol content, peroxidase (PO), polyphenol oxidase (PPO) and phenylalanine ammonia lyase (PAL) activity were estimated at three months after inoculation to find out the bases of resistance When the plants were about to form bunches (six months after inoculation) all the varieties were uprooted and various parameters *viz* number of root knots in 20 g roots and nematode population in 250 g soil and 20 g roots were recorded

Based on the number of galls, indexing was done on 1-5 scale (1= 0 galls/plant, 2= 1-10 galls per plant, 3= 11-30 galls per plant, 4= 31 100 galls per plant, 5= more than 100 galls per plant) and the banana varieties/hybrids were respectively categorized as highly resistant, resistant, moderately resistant, susceptible and highly susceptible (Gitanjalidevi *et al*, 2014) None of the varieties were highly resistant whereas, SH–3640 (AAAB) and SH–3436-6 (AAAA) with mean root knot index of 2 were classified as resistant Nine varieties *viz*, FHIA-1 (AAB), FHIA-3 (AABB), SH–3436-9 (AAAA), TMB × 5295-1 (AAAB), Udayam

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(ABB), Dudhsagar (AAB), Manjeri Nendran II (AAB), Big Ebanga (AAB) and Pisang Nangka (AAB) with root knot index of 3 rated as moderately resistant Seven varieties *viz* , TMP 2829 (AB), Mysore Ethan (AAB), Sugandhi (AAB), Yangambi Km5 (AAA), Bangrier (ABB), Popoulu (AAB) and Pisang Madu (AA) with root knot index of 4 found to be susceptible and rest of the seven varieties *viz* , FHIA 17 (AAAA), FHIA 18 (AAAB), Karpooravally Dwarf (ABB), Pisang Ceylan (AAB), Pisang Jari Buaya (AA), Pisang Buntal (AA) and Robusta (AAA) with root knot index of 5 were classified as highly susceptible

Biometric characters of these varieties did not show notable difference with respect to their susceptibility status Biochemical analysis revealed an increase in total phenol content and in activities of enzyme like polyphenol oxidase, peroxidase, and phenylalanine ammonia lyase in resistant varieties Correlation analysis showed a significant negative correlation between these parameters with number of root knots, root knot index, and population of *M incognita* in root and soil

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*Originals not seen

RESPONSE OF SELECTED BANANA VARIETIES TO ROOT KNOT NEMATODE *Meloidogyne incognita* (Kofoid and White)

By

Neethu N. S.

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ABSTRACT OF THE THESIS

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COLLEGE OF HORTICULTURE

VELLANIKKARA, THRISSUR – 680656

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ABSTRACT

Banana, a dessert fruit for millions, otherwise known as "Apple of Paradise" is botanically *Musa* spp It is one of the most popular fruits in the world in terms of per capita consumption as well as the most widely traded fruit in the world

Among the various pests and diseases of banana, plant parasitic nematodes constitute one of the major limiting factors to banana production causing extensive root damage and serious economic loss throughout the world The root knot nematode *Meloidogyne incognita* (Kofoid and White) alone causes 31 per cent yield reduction in India (Jonathan and Rajendran 2000b) Management of this nematode relies mainly on the repeated use of chemical nematicides which has adverse side effect on environment One of the most effective and economical ways to control plant parasitic nematodes is exploiting host plant resistance

In this context a study entitled "Response of selected banana varieties to root knot nematode, *Meloidogyne incognita* (Kofoid and White)" was carried out in the Department of Agricultural Entomology, College of Horticulture, Vellanikkara and Banana Research Station (BRS), Kannara during 2014-2015 with the objective of screening selected banana varieties/ hybrids against *M incognita* and to elucidate the biochemical basis of resistance

Twenty five banana varieties from the germplasm collection of BRS, Kannara, comprising of nine exotic hybrids, six Indian varieties, nine exotic varieties and a highly susceptible check (Robusta) were screened for their reaction to *M incognita*

Pot culture experiment was conducted at BRS, Kannara in Completely Randomized Design with three replications Nematodes were inoculated @ one second stage juvenile per gram of soil at forty five days after planting Monthly observations on the biometric characters *viz* plant height, pseudostem girth and number of leaves were recorded from the date of inoculation till uprooting (six months after inoculation) At the time of uprooting, root knot number and nematode population in soil and roots were recorded

Based on the number of galls, indexing was done on 1-5 scale and the banana varieties/hybrids were respectively categorized as highly resistant, resistant, moderately resistant, susceptible and highly susceptible (Gitanjalidevi *et al* 2014) None of the varieties were highly

resistant whereas, SH–3640 (AAAB) and SH–3436 6 (AAAA) with mean root knot index of 2 were classified as resistant Nine varieties *viz* FHIA 1 (AAB), FHIA-3 (AABB), SH–3436 9 (AAAA), TMB × 5295-1 (AAAB), Udayam (ABB), Dudhsagar (AAB), Manjeri Nendran II (AAB), Big Ebanga (AAB) and Pisang Nangka (AAB) with root knot index of 3 rated as moderately resistant Seven varieties *viz*, TMP 2829 (AB), Mysore Ethan (AAB), Sugandhi (AAB), Yangambi Km5 (AAA), Bangrier (ABB), Popoulu (AAB) and Pisang Madu (AA) with root knot index of 4 found to be susceptible and rest of the seven varieties viz, FHIA -17 (AAAA), FHIA -18 (AAAB), Karpooravally Dwarf (ABB), Pisang Ceylan (AAB), Pisang Jari Buaya (AA), Pisang Buntal (AA) and Robusta (AAA) with root knot index of 5 were classified as highly susceptible

To study the biochemical basis of resistance, biochemical components like total phenol content, peroxidase (PO), polyphenol oxidase (PPO) and phenylalanine ammonia lyase (PAL) activity were estimated three months after inoculation based on standard procedures

Biochemical analysis revealed a higher total phenol content and enzymes like polyphenol oxidase, peroxidase, and phenylalanine ammonia lyase in resistant varieties A significant negative correlation was observed between the biochemical parameters and number of root knots, root knot index and population of *M incognita* in root and soil

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