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RESEARCH ARTICLE

Interactions between *Radopholus similis* and *Fusarium oxysporum* f. sp. *ubense* causing wilt Complex on Banana

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Abstract

A pot culture experiment was conducted to study the interaction of *Radopholus similis* and *Fusarium oxysporum* f.sp. *ubense* on banana in wilt susceptible cultivar, Nanjanagud Rasabale and wilt tolerant cultivar, Nendran. The results revealed that the combined or *R. similis* inoculated 15 days prior to *Fusarium oxysporum* f.sp. *ubense* has increased the wilt incidence and fastened the wilting with a maximum reduction in plant growth over untreated control. Treatment with *R. similis* alone recorded the highest nematode population in both the cultivars of banana, followed by combined inoculation and *R. similis* inoculated 15 days prior to *Foc*. The combined infection by *R. similis* and *Foc* increased the incidence and severity of *Fusarium* wilt in banana compared to *Fusarium oxysporum* f.sp. *ubense* alone inoculated plants suggesting a positive interaction among the pathogens.

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Introduction

Banana is one of the most important fruit crops and is intensively cultivated in India. It is the second most important fruit crop next to mango, with an annual production of 28.46 mt in 0.78 mha and productivity of 35.7 tonnes per hectare, covering one third (34.22 %) of total fruit production (Anon., 2014a). In Karnataka during 2010-11 banana was grown in an area of 0.11 mha with a production of 2.28 mt with a productivity of 20.40 tonnes per hectare (Anon., 2014b).

Fusarium wilt (Panama disease) is a destructive fungal disease of banana caused by the soil borne fungus *Fusarium oxysporum* f.sp. *ubense* (Smith) Snyder and Hansen (Stover, 1962) (*Foc*) and it is a most destructive disease on many cultivars grown in different banana growing regions of the world (Ploetz *et al.*, 1990). It causes an annual yield loss of 60 to 90 per cent in many countries (Bhuvanendra, 2010). In India, the yield loss by this disease was estimated to be 30 to 40 per cent and in South India alone ranging from 2 to 90 per cent (Thangavelu, 1999). Burrowing nematode (*Radopholus similis* (Cobb) Thorne) is the most serious pathogen on banana causing heavy economic losses (Krishnappa and Reddy, 1993). Crop losses caused by nematodes to bananas are very high, with average annual yield loss of about 20 per cent worldwide (Sasser and Freckman, 1987). Significant economic losses resulting from *R. similis* infestation ranging from 31 to 41 per cent have been reported (Reddy *et al.*, 1992).

Banana production is constrained by biotic and abiotic factors. Among these a complex of fungus and plant parasitic nematodes mostly burrowing nematode (*Radopholus similis* (Cobb) Thorne) and *Fusarium* wilt (*Foc*), is a major cause affecting the fruit yield. Disease complex situations in agricultural crop systems are very common in nature. It has long been shown that fungal pathogens of crop plants interact with plant parasitic nematodes leading to increased disease severity by fungal pathogens (Atkinson, 1892).

The mechanisms of nematode-fungus interactions in disease may differ with the particular nematode, the plant, the interacting pathogen (s) or other factors. The role of the interacting nematode in complex diseases may be to cause wounds that serve as infection points (Mai, *et al.*, 1981), to alter the physiology or biochemistry of the plant leading to increased disease or to modify the expression of host plant resistance (Maheshwari *et al.*, 1995). The

objective of the present experiments was to study the interaction of *R. similis* and *Foc* on wilt susceptible and tolerant cultivars of banana.

Material and methods

Interaction between *R. similis* and *Foc* was studied under greenhouse condition. The uniform 3 months old tissue cultured banana seedlings of Nendran (Plantain) and Nanjanagud Rasabale (Rasthali/ Silk) was potted in 12" pots with sterilized mixture of soil, sand and farm yard manure (2: 1: 1). This study was conducted under the glasshouse belonged to AICRP (Nematodes), ZARS, GKVK, University of Agricultural Sciences, Bangalore during September 2013-14. One month after planting, treatments involving single inoculations of *R. similis* and *Foc* as well as simultaneous and sequential inoculation of both these pathogens with appropriate inoculum was made. Nematode inoculum comprised of 1000 juveniles per kg of soil and a fungal inoculum with size of 200 g of gaint culture per plant was applied. The nematodes required for the studies was cultured on carrot discs as per the procedure described by O'Bannon and Taylor (1968). The virulent pathogen, *Foc*-12 isolate was cultured on a sorghum seeds. About 200 g of slightly cooked sorghum seeds was taken in 1000 ml autoclavable polythene covers and were sterilized at 121 °C at 15 psi for 20 minutes. A few discs of *Foc* from actively growing culture was inoculated under aseptic condition and incubated at 27±5 °C for 30 days. The covers were shaken every two day to get uniform growth. The fungus culture maintained on sorghum seeds medium was added around the root system by removing a small quantity of soil and applying soil over it again after inoculation. There were six treatments and each replicated four times as described below.

Treatments	Abbreviation	Treatment details
T ₁	F	Inoculation with <i>F. oxysporum</i> f.sp. <i> cubense</i> alone
T ₂	N	Inoculation with <i>R. similis</i> alone
T ₃	N+F	Simultaneous inoculation with <i>R. similis</i> and <i>F. oxysporum</i> f.sp. <i> cubense</i>
T ₄	N→F	Inoculation with <i>R. similis</i> followed (15 days) by <i>F. oxysporum</i> f.sp. <i> cubense</i>
T ₅	F→N	Inoculation with <i>F. oxysporum</i> f.sp. <i> cubense</i> followed (15 days) by <i>R. similis</i>
T ₆	C	Control

The growth parameters *viz.*, shoot length, pseudostem girth, number of leaves, leaf area, root length, fresh root weight were recorded with number of lesions per plant, soil and root nematode population was also recorded. The root lesion index was calculated the using the lesion index rating scale (Ravichandra, 1983). Reproduction factor was calculated based on the formula given by Oostenbrink (1966). The wilt incidence at 15 days interval and wilt severity was assessed after 4 months according to Moore *et al.* (1993) as plants were scored for external symptoms on a 1-5 scale. The Rhizome discolouration index was rated on a 1-8 scale (Brake *et al.*, 1995).

Results

There was a considerable variation in the appearance of wilt symptoms in different treatments and also among the cultivars of banana. Wilt symptoms were recorded at 60 days after inoculation in Nanjanagud Rasabale. Whereas, in Nendran initial symptoms occurred only after 75 days after inoculation. The appearance of wilt symptoms was 90 days in *Foc* alone inoculated plants of Nendran and Nanjanagud Rasabale.

The wilting of all the plants was observed at 90 days when inoculated with *R. similis* → *Foc* in Nendran. However, in Nanjanagud Rasabale showed cent per cent wilting at 75 days after inoculation. In general, combined or sequential inoculation of *R. similis* and *Foc* fastened the development of wilting symptoms compared to the *Foc* alone inoculated plants in both the cultivars of banana.

Effect of individual, combined and sequential inoculation of *R. similis* and *Foc* on plant height, number leaves and leaf area, pseudostem girth, Shoot weight, root weight, root length revealed that, significant reduction in the plant height was noticed in all the treatments in both cultivars in comparison to uninoculated control (Table 1).

In wilt tolerant cultivar Nendran, the lowest plant height was recorded in *R. similis* + *Foc* inoculated plants (86.50 cm) and it was on par with *R. similis* → *Foc* (89.50 cm) compared to uninoculated control (102 cm). In wilt susceptible cultivar NanjanagudRasabale, least plant height was noticed in plants inoculated with *R. similis* → *Foc* (79.25 cm) which was on par with *R. similis* + *Foc* (80.75 cm) followed by *Foc* → *R. similis* (83.75 cm) compared to uninoculated control (98.50 cm) (Table 2).

The *R. similis* alone inoculated plant showed no significant difference in the number of functional leaves and leaf area compared to uninoculated control in both the cultivars of banana. In Nanjanagud Rasabale, the minimum number of leaves and leaf area was observed in *R. similis* + *Foc* (5.00, 10901.76 cm²) inoculated plants, *R. similis* → *Foc* (5.50, 12769.97 cm²) and *Foc* → *R. similis* (5.75, 13690.56 cm²) and they were on par with one another. The maximum number of leaves and leaf area was observed in uninoculated control plants with 7.25 leaves and leaf area of 17047.58 cm² (Table 2).

In Nendran, lowest pseudostem girth was recorded in *R. similis* + *Foc* (13.88 cm) inoculated plants and it was on par with *Foc* → *R. similis* (16.13 cm) and *R. similis* → *Foc* (16.25 cm) followed by *R. similis* alone (16.50 cm) compared to uninoculated control (18.75 cm). In NanjanagudRasabale, *R. similis* + *Foc* recorded the minimum pseudostem girth of 13.13 cm respectively compared to uninoculated control plants which yielded maximum pseudostem girth of 17.50 cm respectively (Table 2).

In wilt tolerant cultivar Nendran, the plants inoculated with *R. similis* + *Foc* showed lowest shoot weight of 975.00 g and it was followed by *Foc* → *R. similis* (1055.00 g) and *R. similis* → *Foc* (1075.00 g) compared to uninoculated control (1255.00 g respectively). The shoot weight of NanjanagudRasabale was reduced to 722.50 g in plants inoculated with *R. similis* and *Foc* in combination. While, the maximum shoot weight of 1135.25 g was recorded in uninoculated control plants (Table 2).

The concomitant inoculation of *R. similis* and *Foc* recorded lowest fresh root weight in Nendran (315.00 g) and NanjanagudRasabale (221.25 g), compared to control plants (505.00 and 457.50 g respectively). In Nendran the lowest root length of 31.13 cm was observed in *R. similis* + *Foc* inoculated plants. It was followed by *R. similis* → *Foc* (37.75 cm) and *Foc* → *R. similis* (38.25 cm). In wilt susceptible cultivar, NanjanagudRasabale, the lowest root length was observed in *R. similis* + *Foc* with root length of 26.63 cm. It was followed by *R. similis* → *Foc* with root length of 31.13 and it was on par with *Foc* → *R. similis* with root length of 33.13 cm (Table 2).

The maximum *R. similis* population was recorded in plants inoculated with *R. similis* alone with a population of 372.00, 498.00, 538.00 and 570.00 nema/200 cc of soil at 30, 60, 90 days after inoculation and at harvest respectively (Table 3). The lowest *R. similis* population was observed in plants inoculated with *Foc* → *R. similis* with a population of 338.00, 452.50, 471.00 and 501.00 nema/200 cc of soil at 30, 60, 90 days after inoculation and at harvest respectively. It was on par with *R. similis* + *Foc* (353.00, 463.50, 486.50 and 515.50 nema/200 cc of soil at 30, 60, 90 days after inoculation and at harvest respectively) and *R. similis* → *Foc* (356.00, 478.00, 498.00 and 527.00 nema/200 cc of soil at 30, 60, 90 days after inoculation and at harvest respectively). In Nanjanagud Rasabale, the plants inoculated with *R. similis* alone yielded maximum population at 30, 60, 90 days after inoculation and at harvest with 211.00, 249.00, 275.00 and 294.50 nema/200 cc of soil respectively. At 30 and 60 days after inoculation the same trend was observed with least population of *R. similis* was observed in *Foc* → *R. similis* (187.00; 218.00 nema/200 cc of soil) treatment. It was on par with *R. similis* + *Foc* (193.00; 227.00 nema/200 cc of soil) followed by *R. similis* → *Foc* (205.00; 241.00 nema/200 cc of soil) respectively. But the lowest *R. similis* population was found in *Foc* → *R. similis* (192.50; 206.00 nema/200 cc of soil) followed by *R. similis* + *Foc* (211.00; 226.00 nema/200 cc of soil) and *R. similis* → *Foc* (228.00; 244.00 nema/200 cc of soil) at 90 days after inoculation and at harvest respectively.

The maximum number of nematodes was obtained in *R. similis* alone (221.00, 86.00nema/5g roots) treated plants. The lowest number of *R. similis* was observed in *Foc* → *R. similis* (193.00, 51.00 nema/5g roots), it was on par with *R. similis* + *Foc* (199.00, 55.00 nema/5g roots) and *R. similis* → *Foc* (204.00, 65.00 nema/5g roots). In Nendran and Nanjanagud Rasabale respectively (Table 3).

The reproduction factor was highest in *R. similis* alone treated plants of cultivars viz., Nendran (3.96) and NanjanagudRasabale (1.90). The lowest reproduction factor was in plants treated with *Foc* 15 days prior to *R. similis* in Nendran (3.47) and NanjanagudRasabale (1.29). The plants inoculated with *R. similis* alone showed the maximum number of lesion and lesion index in Nendran (131.00, 4.00), Nanjanagud Rasabale (43.25, 2.00). The lowest number of lesions and lesion index was observe in *Foc* → *R. similis* treatment in Nendran (93.00, 3.00), Nanjanagud Rasabale (18.00, 1.25) (Table 3).

There was 100 percent incidence of wilt in all the treatments except plants received *R. similis* alone treatment and uninoculated control plants (Table 4). The wilt severity based on the leaf severity index differed significantly (Table 4). The wilt severity was lowest in *Foc* alone treated plants in of Nendran (50.00%), Nanjanagud Rasabale (65.00%) and it was followed by plants with *Foc* inoculated 15 days prior to *R. similis* in Nendran (65.00%) and Nanjanagud Rasabale (65.00%).

The maximum wilt severity was observed in plants inoculated with *R. similis* and *Foc* in combination in Nendran, (75.00%), Nanjanagud Rasabale (85.00%). The plants inoculated with *Foc* alone had lowest wilt severity in Nendran (25.00%), It was followed by *Foc* inoculated 15 days prior to *R. similis* produced lowest wilt severity in Kilandy (50.00%), Nanjanagud Rasabale (66.67%). Maximum wilt severity was observed in concomitantly inoculated plants with *R. similis* and *Foc* in Kilandy (66.67%), Nanjanagud Rasabale (91.67%) (Table 4).

Table 1: Influence of *R. similis* and *Foc* on wilt incidence in banana cultivars

Treatments		Number of wilted plants (Out of 3 plants)							
		Days after inoculation							
		15	30	45	60	75	90	105	120
Nendran	F	0	0	0	0	0	1	1	3
	N	0	0	0	0	0	0	0	0
	N+F	0	0	0	0	1	2	2	3
	N→F	0	0	0	0	2	3	3	3
	F→N	0	0	0	0	1	2	3	3
	C	0	0	0	0	0	0	0	0
Nanjanagud Rasabale	F	0	0	0	0	0	1	3	3
	N	0	0	0	0	0	0	0	0
	N+F	0	0	0	1	1	3	3	3
	N→F	0	0	0	1	3	3	3	3
	F→N	0	0	0	0	2	3	3	3
	C	0	0	0	0	0	0	0	0

Table 2: Influence of *R. similis* and *Foc* infection on plant growth parameters, lesion index and wilt score in banana cultivars

Treatments		Plant Height (cm)	No. of Leaves	Leaf Area (cm ²)	Pseudostem Girth (cm)	Shoot weight (g)	Root weight (g)	Root length (cm)
Nendran	F	94.25b	4.25	10307.67	17.25b	1105.00b	487.50a	42.50b
	N	94.75b	4.50	9446.63	16.50c	1112.50b	405.00b	43.25b
	N+F	86.50c	4.00	9167.79	13.88d	975.00c	315.00d	31.13d
	N→F	89.50c	4.25	9891.01	16.25c	1075.00b	325.00cd	37.75c
	F→N	93.25b	4.00	8568.11	16.13c	1055.00b	345.00c	38.25c
	C	102.00a	5.00	11493.22	18.75a	1225.00a	505.00a	48.38a
S. Em ±		1.08	0.25	569.93	0.31	24.83	7.43	0.98
CD @ 5%		3.21	NS	NS	0.93	73.76	22.08	2.90
Nanjanagud Rasabale	F	87.25bc	6.00b	14552.00ab	14.50c	850.00bc	335.00c	43.63c
	N	88.75b	7.50a	16859.03a	15.75b	887.50b	366.25b	50.63b
	N+F	80.75de	5.00b	10901.76c	13.13d	722.50d	221.25f	26.63e
	N→F	79.25e	5.50b	12769.97bc	14.50c	805.00c	251.25e	31.13d
	F→N	83.75cd	5.75b	13690.56bc	14.13cd	856.25bc	282.50d	33.13d
	C	98.50a	7.25a	17047.58a	17.50a	1135.25a	457.50a	53.75a
S. Em ±		1.32	0.40	920.23	0.36	16.52	8.13	0.88
CD @ 5%		3.91	1.19	2734.15	1.06	49.08	24.15	2.60

Means in a column sharing a common letter are not significantly different according to Duncan's Multiple Range Test at P = 0.05.

Table 3: Influence of *R. similis* and *Foc* infection on nematode population, lesion index in banana cultivars

Treatments		Soil Nematode Population (Nos./200 cc soil)				Reproduction Factor (Pf / Pi)	Final root nematode population (per 5 g)	No. of lesions	Lesion Index
		30 DAI	60 DAI	90 DAI	At Harvest				
Nendran	F	0.00d	0.00c	0.00c	0.00c	0.00	0.00c	0.00d	1.00c
	N	372.00a	498.00a	538.00a	570.00a	3.96	221.00a	131.00a	4.00a
	N+F	353.00b	463.50b	486.50b	515.50b	3.57	199.00b	118.25b	3.75a
	N→F	356.00b	478.00ab	498.00b	527.00b	3.66	204.00b	110.25b	4.00a
	F→N	338.00c	452.50b	471.00b	501.00b	3.47	193.00b	93.00c	3.00b
	C	0.00d	0.00c	0.00c	0.00c	0.00	0.00c	0.00d	1.00c
S. Em ±		3.26	7.34	7.92	8.80	-	3.60	3.57	0.10
CD @ 5%		9.68	21.81	23.54	26.14	-	10.69	10.61	0.30
Nanjanagud Rasabale	F	0.00d	0.00d	0.00e	0.00e	0.00	0.00d	0.00e	1.00b
	N	211.00a	249.00a	275.00a	294.50a	1.90	86.00a	43.25a	2.00a
	N+F	193.00bc	227.00bc	211.00c	226.00c	1.41	55.00c	24.25c	1.75a
	N→F	205.00ab	241.00ab	228.00b	244.00b	1.55	65.00b	27.75b	2.00a
	F→N	187.00c	218.00c	192.50d	206.00d	1.29	51.00c	18.00d	1.25b
	C	0.00d	0.00d	0.00e	0.00e	0.00	0.00d	0.00e	1.00b
S. Em ±		3.23	3.87	3.70	4.02	-	2.17	1.17	0.14
CD @ 5%		9.60	11.49	11.00	11.94	-	6.46	3.47	0.43

Initial nematode population: 200/200 cc soil; DAI: Days after Inoculation; Pf: Sum of initial soil and root nematode population; pi: Final nematode population; Means in a column sharing a common letter are not significantly different according to Duncan's Multiple Range Test at P = 0.05.

Table 4: Influence of *R. similis* and *Foc* infection on lesion index, wilt severity in banana cultivars

Treatments		No. of lesions	Lesion Index	Wilt Incidence (%)	Wilt score (LSI) (1-5)	Wilt severity (LSI) (%)	Wilt score (RDI) (1-8)	Wilt severity (RDI) (%)	#Reaction	
									¹ R.similis	² Foc
Nendran	F	0.00d	1.00c	100.00	2.50	50.00 (44.98)b	2.25	25.00 (31.93)b	HS	T
	N	131.00a	4.00a	0.00	1.00	0.00 (0.00)c	1.00	0.00 (0.00)c		
	N+F	118.25b	3.75a	100.00	3.75	75.00 (60.24)a	2.75	33.33 (35.81)ab		
	N→F	110.25b	4.00a	100.00	3.75	75.00 (60.24)a	3.00	37.50 (37.62)ab		
	F→N	93.00c	3.00b	100.00	3.25	65.00 (53.91)a	3.50	41.67 (41.36)a		
	C	0.00d	1.00c	0.00	1.00	0.00 (0.00)c	1.00	0.00 (0.00)c		
S. Em ±		3.57	0.10	-	-	2.62	0.25	1.88		
CD @ 5%		10.61	0.30	-	-	7.78	0.74	5.59		
Nanjanagud Rasabale	F	0.00e	1.00b	100.00	3.25	65.00 (53.91)b	6.25	75.00 (62.30)b	T	HS
	N	43.25a	2.00a	0.00	1.00	0.00 (0.00)c	1.00	0.00 (0.00)c		
	N+F	24.25c	1.75a	100.00	4.25	85.00 (70.05)a	7.50	91.67 (79.62)a		
	N→F	27.75b	2.00a	100.00	3.75	75.00 (60.24)ab	6.50	79.17 (64.62)b		
	F→N	18.00d	1.25b	100.00	3.25	65.00 (53.91)b	5.75	66.67 (58.42)b		
	C	0.00e	1.00b	0.00	1.00	0.00 (0.00)c	1.00	0.00 (0.00)c		
S. Em ±		1.17	0.14	-	-	3.51	0.28	3.28		
CD @ 5%		3.47	0.43	-	-	10.44	0.82	9.76		

LSI: Leaf Severity Index, RDI: Rhizome Discolouration Index, 1- Based on the Lesion Index of nematode alone treatment; 2- Based on the Wilt score (LSI and RDI) in fungus alone treatment; Means in a column sharing a common letter are not significantly different according to Duncan's Multiple Range Test at $P = 0.05$.

Discussion

In the present study, the combined or sequential inoculation of *R. similis* and *Foc* fastened the appearance of wilt symptoms. This is in agreement Abdel Hadiet *et al.* (1987) reported that combined inoculation of banana roots with *Foc* and *R. similis* induced the lesions after one week compared to untreated control. In the presence of nematodes 10 days prior to fungus/or and bacterium accelerated the wilt disease development to the maximum (Pathak *et al.*, 1999). Jonathan and Rajendran (1998), reported that the Panama wilt disease symptom was significantly higher when nematode, *M. incognita* inoculated first followed by fungus and this complex had reduced the plant growth significantly. The nematode acted as a predisposing factor for the fungal pathogen by causing injury on the root surface as well as weakens the root tissues by causing root lesions and galling, thereby the fungal pathogen might have easy access for causing greater damage, as also reported by Rao and Krishnappa (1994).

The present investigations with significant reduction in plant height, pseudostem girth, shoot weight, fresh root weight and root length was noticed in simultaneous inoculation of *R. similis* and *Foc* over untreated control. However, *Foc* inoculated individually caused greater reduction in plant growth than *R. similis* alone. In case of sequential inoculation of *R. similis* and *Foc*, greatest reduction in plant growth was observed in inoculation of *R. similis* 15 days prior to *Foc* and also with *Foc* 15 days prior to *R. similis* over control and are in agreement with Sundararaju and Thangavelu (2009), who have reported that maximum reduction of plant growth was observed in plants inoculated with *P. coffeae*, *M. incognita* and *Foc* together. Bhabeshet *et al.* (2009) recorded greater damage in simultaneous inoculation of fungus and nematode might be attributed to the prior invasion of nematodes into the roots has made the host more favourable for fungal infection with metabolically rich substrate and nematode might also modified the rhizosphere favouring of the fungal growth.

The present findings of inoculation with *R. similis* alone recorded the highest nematode population in all the cultivars of banana, followed by combined and *R. similis* inoculated 15 days prior to *Foc*. The least nematode population was observed when *Foc* was inoculated 15 days prior to *R. similis*. Inoculation of *R. similis* alone gave the pathogen free accesses to all parts of the roots without hindrances from other pathogens hence enhancing nematode multiplication irrespective of host. High nematode population shows that the rate of reproduction was high as it correlated with both high reproduction factor and high lesion numbers and lesion index and are in confirmation with Poornimaet *et al.* (2007) and Pathak *et al.* (1999) who observed a negative interaction between the *Foc* and *H. multicinctus*. The nematode population and corm lesion index were greatest when nematodes were inoculated alone. Further, they reported that concomitant presence of the fungus and nematodes adversely affected the nematode population. This also similar in *M. incognita* and *Foc* interaction.

The reduction of the nematode population in the presence of the fungus may be attributed to competition for space and food resources, or due to mycotoxins produced by the fungus or other physiological changes caused in the roots by the presence of the fungus. Fungal toxins that affect cell membranes, mechanical plugging of sieve plates or air embolisms that cause vascular occlusion and consequent water deficits and plant wilting (Pegg, 1989) might have led to decline in nematode population. The fungal pathogen not only hinders the growth and multiplication of plant parasites and also changes the nematode community in the rhizosphere of infected plants.

The present findings revealed that the combined infection by *R. similis* and *Foc* increased the incidence and severity of *Fusarium* wilt in all six susceptible and tolerant cultivars of banana compared to *Foc* alone inoculated plants and it was on par with *R. similis* inoculated 15 days prior to *Foc*. The wilt severity of *Foc* inoculated 15 days prior to *R. similis* was on par with the *Foc* alone inoculated plants in both the cultivars and are in agreement with Abdel Hadiet *et al.* (1987), who reported that inoculation of banana roots with *Foc* and *R. similis* induced lesions after one week. The percentage of rotted roots was 36.5% with the nematode alone, 47.8 per cent with both organisms and four per cent with the fungus alone. Further, Atkinson (1892) a pioneer in studying the nematode fungal wilt complex, reported as the presence of *M. incognita* along with *F. oxysporum* in the rhizosphere of cotton plants increased the severity of wilt caused by the fungus. Similar synergistic interaction was observed between the *M. incognita* and *Foc* in concomitant and sequential inoculations, The Panama wilt disease in terms of corm rot was higher when nematode followed fungus and in concomitant inoculations of the pathogens as reported by Jonathan and Rajendran (1998). The maximum wilt was observed in the presence of *M. incognita* 10 days prior to *Foc* and *Pseudomonas solanacearum*. Presence of all the three pathogens together had more deleterious effects on banana plants (Pathak *et al.*, 1999). Further, Sundararaju and Thangavelu (2009) revealed that the plants receiving inoculum

of anyone of the nematodes (*P. coffeae* and *M. incognita*) or both inoculated simultaneously followed by the *Foc* resulted in the early onset and increased severity of the *Fusarium* wilt. The necrotic damage caused by *P. coffeae* and the secondary infection of *Fusarium* wilt pathogen (*Foc*) together can devastate banana plantations sometimes to the tune of 44-60% (Jonathan and Rajendran, 2000).

Mechanical wounding or injury by *R. similis* was necessary for *Foc* to cause reddish-brown lesions. The complex infection caused by plant parasitic nematodes and *Foc* gave rise to a necrotic and reduced root system, which in turn, resulted in a reduction in the uptake and transportation of water and nutrients by the plant (Poornima et al., 2007).

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