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Effects of the *Mi-1*, *N* and *Tabasco* Genes on Infection and Reproduction of *Meloidogyne mayaguensis* on Tomato and Pepper Genotypes

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Abstract: *Meloidogyne mayaguensis* is a damaging root-knot nematode able to reproduce on root-knot nematode-resistant tomato and other economically important crops. In a growth chamber experiment conducted at 22 and 33°C, isolate 1 of *M. mayaguensis* reproduced at both temperatures on the *Mi-1*-carrying tomato lines BHN 543 and BHN 585, whereas *M. incognita* race 4 failed to reproduce at 22°C, but reproduced well at 33°C. These results were confirmed in another experiment at 26 ± 1.8°C, where minimal or no reproduction of *M. incognita* race 4 was observed on the *Mi-1*-carrying tomato genotypes BHN 543, BHN 585, BHN 586 and 'Sanibel', whereas heavy infection and reproduction of *M. mayaguensis* isolate 1 occurred on these four genotypes. Seven additional Florida *M. mayaguensis* isolates also reproduced on resistant 'Sanibel' tomato at 26 ± 1.8°C. Isolate 3 was the most virulent, with reproduction factor (Rf) equal to 8.4, and isolate 8 was the least virulent (Rf = 2.1). At 24°C, isolate 1 of *M. mayaguensis* also reproduced well (Rf ≥ 1) and induced numerous small galls and large egg masses on the roots of root-knot nematode-resistant bell pepper 'Charleston Belle' carrying the *N* gene and on three root-knot nematode-resistant sweet pepper lines (9913/2, SAIS 97.9001 and SAIS 97.9008) carrying the *Tabasco* gene. In contrast, *M. incognita* race 4 failed to reproduce or reproduced poorly on these resistant pepper genotypes. The ability of *M. mayaguensis* isolates to overcome the resistance of tomato and pepper genotypes carrying the *Mi-1*, *N* and *Tabasco* genes limits the use of resistant cultivars to manage this nematode species in infested tomato and pepper fields in Florida.

Key words: *Capsicum annuum*, bell pepper, resistance, root-knot nematodes, *Solanum lycopersicum*, sweet pepper.

Meloidogyne mayaguensis was first reported in the continental US in 2002 (Brito et al., 2004). This nematode is of special interest because of its ability to overcome root-knot nematode resistance genes in some economically important crops. Populations of *M. mayaguensis* from Côte d'Ivoire and Burkina Faso (Fargette et al., 1996), Senegal (Duponnois et al., 1995) and Cuba (Rodríguez-Hernández et al., 2001; Rodríguez et al., 2003) have been reported to overcome the *Mi-1* gene in tomato (*Solanum lycopersicum* L.) cultivars and other unidentified root-knot nematode resistance genes in soybean (*Glycine max* (L.) Merrill) 'Forrest' and sweetpotato (*Ipomoea batatas* (L.) Lam.) 'CDH' (Fargette, 1987).

The *Mi-1* gene confers resistance in tomato to the three most common warm-climate root-knot nematodes species, *M. arenaria*, *M. incognita* and *M. javanica* (Williamson, 1999). No information is available on the ability of *M. mayaguensis* to reproduce on root-knot nematode-resistant pepper (*Capsicum annuum* L.) cultivars. Sources of genetic resistance in pepper to *M. arenaria*, *M. hapla*, *M. incognita* and *M. javanica* were found in two wild lines of *Capsicum chinense* and one of *Capsicum frutescens* (Di Vito and Saccardo, 1979, 1982; Di Vito et al., 1991). Several single dominant genes in pepper, including the *N* gene (Di Vito et al., 1993b; Fery et al., 1998; Thies and Fery, 2000), the *Me-1* and *Me-3* genes (Hendy et al., 1985; Castagnone-Sereno et al., 2001; Djian-Caporalino et al., 2001) and the *Tabasco* gene in pepper lines such as line 89422 (Di Vito and Saccardo, 1986), 9913/2, SAIS 97.9001 and SAIS 97.9008 (M. Di Vito and F. Saccardo, unpub. data), also confer resistance to the three major root-knot nematode species (Di Vito et al., 1993a). The dominant *N* gene in bell pepper 'Charleston Belle' confers resistance to *M. arenaria* races 1 and 2, *M. javanica* (Thies and Fery, 2000) and *M. incognita* (Di Vito et al., 1993b; Fery et al., 1998). Two dominant genes in wild line 56–547/7 of *C. chacoense* and line 46–530/7 of *C. chinense* and a recessive gene in PI 159237 and PI 159256 of *C. annuum* (Di Vito and Saccardo, 1986) confer resistance to *M. javanica* and *M. arenaria*, respectively (Di Vito et al., 1993b).

The instability of the root-knot nematode resistance genes in both tomato and pepper at high soil temperature limits their usefulness to manage *Meloidogyne* spp. in vegetable-production in warm climates. Although the *Mi-1* gene in tomato is not stable at high soil temperatures (Dropkin, 1969; Ammati et al., 1986; Haroon et al., 1993), this has not been a problem in processing tomato in California (J. O. Becker, UC Riverside, pers. comm.). A recent report in Florida also showed that tomato with the *Mi-1* gene greatly suppressed root galling by *M. javanica* in both fall and spring tomato crops grown under polyethylene mulch (Rich and Olson, 1999). Similarly, galling caused by root-knot nematode was greatly reduced by the *N* gene in fall and spring bell pepper crops grown under polyethylene mulch (Thies et al., 2008).

The resistance to root-knot nematodes conditioned by some unidentified genes in pepper was stable at high soil temperatures (Djian-Caporalino et al., 2001). The wild lines 24, 28 and 56 of *C. chinense*, 32 of *C. chacoense*, 79 of *C. frutescens* and 92–3 of *C. annuum*, resistant to

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the Italian populations of *M. incognita*, *M. javanica* and *M. arenaria* (Di Vito et al., 1991), maintained their resistance at a very high soil temperature (38°C) (Di Vito et al., 1995; Di Vito and Saccardo, 1996). The resistance conferred by the *N* gene in bell pepper 'Charleston Belle' was only partially lost at soil temperatures of 28 to 32°C under controlled conditions (Thies and Fery, 1998). The objectives of this study were to (i) determine whether *M. mayaguensis* from Florida is able to overcome the *Mi-1*-mediated resistance in tomato, the *N* gene in bell pepper 'Charleston Belle' and the *Tabasco* gene in three pepper lines; and (ii) determine the virulence of seven isolates of *M. mayaguensis* to a root-knot nematode-resistant tomato cultivar.

Materials and Methods

Nematode source: Meloidogyne mayaguensis and *M. incognita* isolates were originally collected from field populations in Florida. The nematode species were identified using morphometrics, perineal patterns and esterase and malate dehydrogenase phenotypes. A single egg mass isolate from each field population was reared on tomato 'Rutgers' in separate greenhouses. The isolates *of M. mayaguensis* were: isolate 1 (DPI: N01–304–15B) and isolate 2 (N01–283–14B) collected from unidentified ornamental plants from Broward and Palm Beach Counties, respectively; isolate 3 (N02–341–4B) obtained from tomato from Hendry County; isolate 4 (N02–817–8B) from cape honeysuckle (*Tecomaria capensis* (Thunb.) Spach) from Palm Beach County; isolate 5 (N03–282–1B) from basil (*Ocimum* sp.) from Martin County; isolate 6 (N04–503–2B) from tomato from Hendry County; isolate 7 (N04–681–3B) from trumpet flower (*Brugmansia* sp.) from Alachua County; and isolate 8 (N04–1180–4B) from bottle brush (*Callistemon citrinus* (Curtis) Skeels) from Nassau County. The isolate of *M. incognita* race 4 was originally isolated from tobacco (*Nicotiana tabacum* L.), Green Acres Research Farm, University of Florida, Alachua County, FL.

Tomato tests: The reproduction of *M. mayaguensis* and *M. incognita* race 4 on resistant and susceptible tomato genotypes was compared in three experiments. Experiments 1 and 2 were conducted with *M. mayaguensis* isolate 1 and *Mi-1*-carrying tomato genotypes BHN 585 and BHN 586 under constant environmental temperatures of 22 and 33°C, respectively, in growth chambers (Walker et al., 1993) with 60% RH. Experiment 3 was conducted at 26 ± 1.8°C in a growth room also with *M. mayaguensis* isolate 1 and four *Mi-1*-carrying tomato genotypes (Table 1). In experiment 4, the reproduction of seven *M. mayaguensis* isolates on *Mi-1*-carrying tomato cultivar 'Sanibel' was evaluated at 26 ± 1.8°C in a growth room. Thirty-day-old seedlings grown in vermiculite (Grace Canada, Ajax, Ontario) were transplanted individually into 10- (growth chambers) or 15-cm-diam. (growth room) clay pots containing pasteurized soil. Five days after transplanting, each seedling was inoculated with 2,500 (exp. 1, 2) or 5,000 eggs (exp. 3, 4). Inoculum was dispensed into four holes (1.5-cm deep) around the plant base using a micropipette. Seedlings were arranged in a completely randomized design with four (exp. 1, 2) or six replicates (exp. 3, 4). Plants were watered daily with equal amounts of water and fertilized weekly with Peters Professional 20–20–20 (United Industries, St. Louis, MO). Experiments 1–2 and 3–4 were evaluated 39 and 60 d after inoculation (DAI), respectively. Root systems were harvested, washed gently, stained (Thies et al., 2002) and then rated for nematode reproduction with a gall index (GI) and an egg mass index (EMI), using a 0 to 5 scale (Taylor and Sasser, 1978). Eggs were extracted from the entire root systems using the NaOCl method (Hussey and Barker, 1973) as modified by Boneti and Ferraz (1981). Nematode reproduction was assessed by calculating the reproduction factor (Rf = Pf/Pi), where Pi = initial inoculum level and Pf = final egg recovery (Sasser et al., 1984). Egg mass index, Rf and eggs per gram of roots (exp. 4 only) were used to assess the effectiveness of resistance genes on the reproduction of *M. mayaguensis* and *M. incognita*.

Pepper tests: Four root-knot nematode-resistant pepper genotypes (Table 1) were compared with the root-

Table 1. Root-knot nematode-resistant tomato and pepper genotypes used in this study.

	Genotype	Seed source	Root-knot nematode resistance gene
Tomato	Sanibel	Seminis Vegetable Seeds, Oxnard, CA	*Mi-1*
	BHN 543	BHN Seed, Immokalee, FL	*Mi-1*
	BHN 585	BHN Seed, Immokalee, FL	*Mi-1*
	BHN 586	BHN Seed, Immokalee, FL	*Mi-1*
Pepper	*C. annuum* var. 'Charleston Bell'	U. S. Vegetable Lab., USDA, Charleston, SC	*N*
	C. annuum Line 9913/2	Istituto Protezione Piante, CNR, Bari, Italy	*Tabasco*
	C. annuum Line SAIS 97.9001	SAIS Sementi, Cesena, Italy	*Tabasco*
	C. annuum Line SAIS 97.9008	SAIS Sementi, Cesena, Italy	*Tabasco*

TABLE 2. Reproduction factor (Rf), egg mass (EMI) and gall indices (GI) of *meloidogyne mayaguensis* (isolate 1) and *M. incognita* race 4 on two *Mi-1*-carrying tomato cultivars and the susceptible tomato 'Rutgers' at 22 and 33°C, experiments 1 and 2.

Tomato genotype	Rf[a]				EMI[b]				GI[b]			
	22°C		33°C		22°C		33°C		22°C		33°C	
	Mm[c]	Mi4[c]	Mm	Mi4	Mm	Mi4	Mm	Mi4	Mm	Mi4	Mm	Mi4
BHN 585	7.4 aA[d]	0.0 bB	8.7 bA	3.4 aB	5.0 aA	0.0 bB	5.0 aA	3.8 bB	5.0 aA	0.0bB	4.8 aA	3.8 bB
BHN 586	15.0 aA	0.3 bB	9.9 bA	4.3 aB	5.0 aA	0.8 bB	4.0 bA	4.3 bA	5.0 aA	0.8 bB	4.8 aA	4.5 aA
'Rutgers'	14.0 aA	9.6 aA	47.3 aA	4.7 aB	5.0 aA	4.5 aA	5.0 aA	5.0 aA	5.0 aA	4.8 aA	5.0 aA	4.5 aA

[a] Rf = final population/initial population.
[b] Gall and egg mass indices: 0–5 scale where 0 = no galls or egg masses, 1 = 1–2 galls or egg masses, 2 = 3–10 galls or egg masses, 3 = 11–30 galls or egg masses, 4 = 31–100 galls or egg masses and 5 = >100 galls or egg masses/root system.
[c] Mm = *Meloidogyne mayaguensis*; Mi4 = *M. incognita* race 4.
[d] Means are average of duplicate tests, each with four replicates. Data on reproduction factor, egg mass and gall indices were transformed with √×+1 before analysis and untransformed data are presented in table. Means within a column followed by the same lowercase letters and within the rows followed by the same uppercase letters are not different at $P \leq 0.05$ according to ANOVA and Tukey's HSD Test.

knot nematode-susceptible 'Keystone Resistant Giant' pepper in a growth chamber (Walker et al., 1993) at 24°C in two experiments. *Meloidogyne mayaguensis* (isolate 1) and *M. incognita* race 4 were used in this study. Each seedling (35-d-old) growing in a clay pot (10-cm-diam.) was inoculated with 2,500 eggs. Treatments were set up in a completely randomized design. Plants were watered daily and fertilized as described for the tomato studies. Root systems were harvested at 45 DAI. Reproduction factor, GI and EMI were determined as described above.

Statistical analysis: Data from nematode EMI, GI and Rf were subjected to ANOVA using JMPIN (SAS Institute Inc., Cary, NC), and treatment means were separated by Tukey's HSD test at $P \leq 0.05$. Gall index and EMI data from tomato and pepper tests were transformed by √x+1 to equalize the error variances prior to analysis of variance. Untransformed data are presented in the tables.

RESULTS

Tomato tests: Isolate 1 of *M. mayaguensis* reproduced on the susceptible tomato cultivar and on both the *Mi-1*-carrying tomato genotypes BHN 585, BHN 586 at 22 and 33°C (Table 2). There also was reproduction at 26 ± 1.8°C on 'Sanibel' (Tables 3, 4), BHN 543, BHN 585 and BHN 586 (Table 3). *Meloidogyne incognita* reproduced well on the *Mi-1*-carrying tomato genotypes at 33°C, but there was no or minimal reproduction at 22°C (Table 2). The Rf of *M. mayaguensis* (isolate 1) on *Mi-1* tomatoes at 22 and 33°C was higher than that of *M. incognita* (Table 2). Similar results were observed at 26 ± 1.8°C; *M. incognita* reproduced poorly on the *Mi-1*-carrying tomatoes, and the Rf values varied from 0.1 to 0.2 (Table 3). The average Rf of *M. mayaguensis* (isolate 1) on the *Mi-1*-carrying tomatoes ranged from 7.4 on BHN 585 to 15.0 on BHN 586 at 22°C and from 8.7 to 9.9 on BHN 585 and BHN 586 tomatoes at 33°C, respectively (Table 2). However, at 26 ± 1.8°C, BHN 543 and BHN 585 tomatoes supported more *M. mayaguensis* reproduction ($P < 0.05$) than 'Sanibel' tomato (Table 3). The Rf of this nematode isolate ranged from 85.5 on 'Sanibel' to 157.9 on BHN 585 (Table 3). All root-knot nematode-resistant tomato genotypes were susceptible (Rf ≥ 1) to *M. mayaguensis* (isolate 1) regardless of the temperature (Tables 2, 3).

Isolate 1 of *M. mayaguensis* produced higher egg mass and galling indices on the *Mi-1* tomato genotypes at 22°C (Table 2) and at 26 ± 1.8°C in experiment 3 than *M. incognita* (Table 3). There were no differences ($P >$

TABLE 3. Reproduction factor (Rf), egg mass (EMI) and galling indices (GI) of *Meloidogyne mayaguensis* (isolate 1) and *M. incognita* race 4 on four *Mi-1*-carrying tomato cultivars and the susceptible tomato 'Rutgers' at 26 ± 1.8°C in experiment 3.

Tomato cultivar/genotype	Rf[a]		EMI[b]		GI[b]	
	Mm[c]	Mi4[c]	Mm	Mi4	Mm	Mi4
'Sanibel'	85.5 bA[d]	0.2 bB	5.0 aA	1.3 bB	5.0 aA	1.5 bB
BHN 543	156.7 aA	0.1 bB	5.0 aA	0.7 bB	5.0 aA	0.8 bB
BHN 585	157.9 aA	0.2 bB	5.0 aA	1.7 bB	5.0 aA	1.8 bB
BHN 586	118.0 abA	0.2 bB	5.0 aA	1.2 bB	5.0 aA	1.8 bB
'Rutgers'	100.8 bA	107.0 aA	5.0 aA	5.0 aA	5.0 aA	5.0 aA

[a] Rf = final population/initial population.
[b] Gall and egg mass indices: 0–5 scale where 0 = no galls or egg masses, 1 = 1–2 galls or egg masses, 2 = 3–10 galls or egg masses, 3 = 11–30 galls or egg masses, 4 = 31–100 galls or egg masses and 5 = >100 galls or egg masses/root system.
[c] Mm = *Meloidogyne mayaguensis*; Mi4 = *M. incognita* race 4.
[d] Means are average of duplicate tests, each with six replicates. Data on reproduction factor, egg mass and gall indices were transformed with √×+1 before analysis and untransformed data are presented in table. Means within a column followed by the same lowercase letter and within the rows followed by the same upper case letter are not different at $P \leq 0.05$ according to Tukey's HSD Test.

TABLE 4. Reproduction factor (Rf), eggs per gram of roots, galling (GI) and egg mass indices (EMI) of seven isolates of *Meloidogyne mayaguensis* on *Mi-1* carrying 'Sanibel' and susceptible 'Rutgers' tomatoes under growth room conditions at 26 ± 1.8°C in experiment 4.

Isolates of *M. mayaguensis*	Rf[a]		Eggs/g root		GI[b]		EMI[b]	
	'Sanibel'	'Rutgers'	'Sanibel'	'Rutgers'	'Sanibel'	'Rutgers'	'Sanibel'	'Rutgers'
Isolate 2	6.8 bB[c]	32.2 aA	3656.7 bB	19025.2 aA	4.7 aA	4.9 aA	4.6 aB	4.9 aA
Isolate 3	8.4 aB	33.8 aA	4587.4 bB	22439.0 aA	4.6 aA	5.0 aA	4.5 aB	4.9 aA
Isolate 4	5.6 bcB	30.7 aA	3062.4 bB	17095.5 aA	4.6 aA	5.0 aA	4.2 abB	5.0 aA
Isolate 5	3.0 dB	31.4 aA	3083.4 bB	18326.8 aA	3.8 bcB	5.0 aA	3.4 bB	4.9 aA
Isolate 6	4.0 cB	35.5 aA	2123.6 bB	19732.9 aA	3.9 bB	4.9 aA	3.7 bB	4.9 aA
Isolate 7	6.8 bB	36.4 aA	2910.0 bB	26459.9 aA	3.9 bB	5.0 aA	3.2 bcB	5.0 aA
Isolate 8	2.1 dB	29.7 aA	1991.6 bB	17018.1 aA	3.7 bcB	4.8 abA	2.9 cB	4.8 aA

[a] Rf = final population/initial population.
[b] Gall and egg mass indices: 0–5 scale where 0 = no galls or egg masses, 1 = 1–2 galls or egg masses, 2 = 3–10 galls or egg masses, 3 = 11–30 galls or egg masses, 4 = 31–100 galls or egg masses and 5 = >100 galls or egg masses/root system.
[c] Means are average of duplicate tests, each with six replicates. Data on reproduction factor, egg mass and gall indices were transformed with $\sqrt{x+1}$ and data on eggs per gram roots were transformed with $[\log_{10}(x+1)]$ before analysis, and untransformed data are presented in table. Means within a column followed by the same lowercase letters and within the rows followed by the same uppercase letters are not different at $P \leq 0.05$ according to Tukey's HSD Test.

0.05) in the EMI and GI (Table 2) between both nematodes at 33°C, except that *M. mayaguensis* (isolate 1) had higher EMI (EMI = 5.0) and GI (GI = 4.8) on BHN 585 tomato than *M. incognita* (GI = 3.8; EMI = 3.8) (Table 2). Conversely, there were no differences of the Rf, EMI and GI on the susceptible 'Rutgers' tomato inoculated with either nematode regardless of the temperature, except for *M. mayaguensis*, which had higher reproduction (Rf = 47.3) than *M. incognita* (Rf = 4.7) at 33°C ($P < 0.05$) (Tables 2, 3).

Seven isolates of *M. mayaguensis* evaluated in experiment 4 were virulent to *Mi-1*-carrying 'Sanibel' tomato; however, isolate 3 was the most virulent (Rf = 8.4), and isolate 8 was the least (Rf = 2.1) (Table 4). All these isolates produced similar number of eggs per gram of roots ($P > 0.05$) on 'Sanibel' tomato (Table 4), but all isolates had higher Rf, eggs per gram of roots and EMI on 'Rutgers' than 'Sanibel' tomato ($P < 0.05$) (Table 4). The difference in the Rf values between experiment 3 and 4 (Tables 3, 4) might be due to the different *M. mayaguensis* isolates used in these experiments and smaller root systems obtained in experiment 4 (data not shown).

Pepper tests: Meloidogyne mayaguensis (isolate 1) had a higher Rf and produced more egg masses and galls ($P < 0.05$) on all the root-knot nematode-resistant pepper genotypes than *M. incognita* race 4 (Table 5). *Meloidogyne mayaguensis* had a higher Rf (79.9) on the *N*-carrying bell pepper 'Charleston Belle' than on the susceptible 'Keystone Resistant Giant' (Rf = 34.4). *Meloidogyne incognita* did not induce any root galls, and no egg mass formation was observed on 'Charleston Belle' bell pepper, while *M. mayaguensis* produced visible galls and numerous, large egg masses on 'Charleston Belle' (Table 5) and the pepper lines. Very few galls and egg masses were observed in all pepper lines inoculated with *M. incognita* race 4 (Table 5). *Meloidogyne mayaguensis* reproduced equally ($P > 0.05$) on the three root-knot nematode-resistant pepper lines 9913/2, SAIS 97.9001 and SAIS 97.9008, whereas *M. incognita* reproduced

TABLE 5. Reproduction factor (Rf), egg mass (EMI) and galling (GI) indices of *Meloidogyne mayaguensis* (isolate 1) and *M. incognita* race 4 on root-knot nematode resistant peppers and a susceptible cultivar 'Keystone Resistant Giant' at 24°C in two separate experiments.

Genotypes	Rf[a]		EMI[b]		GI[b]	
	Mm[c]	Mi4[c]	Mm	Mi4	Mm	Mi4
Experiment 1[d]						
'Charleston Belle'	79.9 aA[c]	0.1 bB	5.0 aA	0.0 bB	4.2 aA	0.0 bB
'Keystone Resistant Giant'	34.4 bB	81.2 aA	5.0 aA	4.3 aA	5.0 aA	4.8 aA
Experiment 2[d]						
Line 9913/2	42.3 aA[e]	0.10 bB	4.8 aA	0.8 bB	4.8 aA	0.9 bB
SAIS 97.9001	29.1 aA	0.01 bB	4.3 aA	0.3 bB	3.5 bA	0.6 bB
SAIS 97.9008	51.4 aA	0.04 bB	4.6 aA	0.4 bB	4.0 bA	0.7 bB
'Keystone Resistant Giant'	42.6 aA	34.8 aA	4.2 aA	4.0 aA	4.7 aA	4.2 aA

[a] Rf = final population/initial population.
[b] Gall and egg mass indices: 0–5 scale where 0 = no galls or egg masses, 1 = 1–2 galls or egg masses, 2 = 3–10 galls or egg masses, 3 = 11–30 galls or egg masses, 4 = 31–100 galls or egg masses and 5 = >100 galls or egg masses/root system.
[c] Mm = *Meloidogyne mayaguensis*; Mi4 = *M. incognita* race 4.
[d] Experiments 1 and 2 were performed at different times, thus analyzed separately.
[e] Means are average of duplicate tests, each with six replicates. Data on reproduction factor, egg mass and gall indices were transformed with $\sqrt{x+1}$ before analysis, and untransformed data are presented in table. Means within a column followed by the same lowercase letters and within the rows followed by the same upper case letters are not different at $P \leq 0.05$ according to Tukey's HSD Test.

poorly (Table 5). The Rf values of *M. mayaguensis* on the pepper lines ranged from 51.4 on SAIS 97.9008 to 29.1 on SAIS 97.9001, whereas the EMI values ranged from 4.3 to 4.8 on SAIS 97.9001 and 9913/2, respectively (Table 5). The GI values ranged from 3.5 to 4.8 on SAIS 97.9001 and 9913/2, respectively. Based on Rf values, all root-knot nematode-resistant pepper genotypes were susceptible to *M. mayaguensis* and resistant to *M. incognita* race 4 (Tables 5).

Discussion

The isolates of *M. mayaguensis* from Florida were able to overcome the resistance of the *Mi-1* gene in four tomato genotypes, the *N* gene in the bell pepper 'Charleston Belle' and the *Tabasco* gene in pepper lines. All these genes confer resistance to *M. arenaria*, *M. incognita* and *M. javanica*. The results of this study indicated that *M. mayaguensis* from Florida reproduced well at 22, 26 ± 1.8 and 33°C on *Mi-1* gene-carrying tomato and at 24°C on root-knot nematode-resistant pepper genotypes, whereas *M. incognita* reproduced well at 33°C and had little or no reproduction at 22°C when inoculated on the same genotypes. These results confirm previous studies that have reported the instability of the *Mi-1* gene to *M. incognita* at high soil temperatures (Dropkin, 1969; Ammati et al., 1986). It is worth mentioning that the soil temperatures in the experiments carried out in the growth chambers were monitored manually at different intervals during the duration of the experiments. The difference between the soil and environmental temperatures within each growth chamber during these studies was negligible.

Isolate 1 of *M. mayaguensis* reproduced well on the *Mi-1* resistance gene in 'Sanibel', BHN 543, BHN 585 and BHN 586 tomato genotypes and the *N* resistance gene in bell pepper 'Charleston Belle', as well as the *Tabasco* gene in pepper lines 9913/2, Sais 97.9001 and Sais 97.9008. All the root-knot nematode-resistant tomato and pepper genotypes evaluated were susceptible to *M. mayaguensis* isolate 1 and resistant to *M. incognita* race 4. Both nematodes produced similar EMI and GI and reproduced well on the susceptible 'Rutgers' tomato and 'Keystone Resistant Giant' pepper used as control. This is the first report of *M. mayaguensis* breaking the resistance of root-knot nematode resistance genes in bell pepper and sweet pepper; however, virulent isolates of *M. arenaria* and *M. incognita* have been reported to overcome the resistance conferred by gene *Me-3* in pepper line HDA149 (Castagnone-Sereno et al., 2001). Likewise, virulent isolates of *M. incognita* collected in Uruguay reproduced on *Mi-1*-carrying tomato 'Nikita' and on root-knot nematode-resistant peppers 'Atlante', 'Carolina Wonder' and Charleston Belle' (Piedra Buena et al., 2005). In contrast, the *Me-1* resistance gene in the pepper line HDA330 has been reported to be effective against *M. incognita* virulent isolates (Castagnone-Sereno et al., 2001); however, no data is available on the reproduction of *M. mayaguensis* on *Me-1*-carrying peppers.

Eight isolates of *M. mayaguensis* used in this study were virulent to the *Mi-1*-carrying 'Sanibel' tomato; however, seven of eight isolates produced more egg masses, more eggs per gram of root and had a higher Rf on the susceptible 'Rutgers' than on 'Sanibel' tomato. These differences may indicate that the *Mi-1* gene has a negative effect on the ability of these *M. mayaguensis* isolates to reproduce on *Mi-1*-carrying resistant tomato genotypes. *Meloidogyne mayaguensis* isolate 1, however, reproduced at similar levels on the susceptible and resistant tomato genotypes, as well as on susceptible and resistant pepper genotypes, except on 'Charleston Belle' pepper. These results suggest that there is not only variability in the virulence among the isolates of *M. mayaguensis* but also among root-knot nematode resistance genes regarding to their effectiveness to reduce *M. mayaguensis* reproduction. The reproduction of other isolates of *M. mayaguensis* in *Mi-1*-carrying tomato has been reported in countries in Africa, the Caribbean basin and South America. Populations of *M. mayaguensis* have been found reproducing on the *Mi-1*-carrying 'Rossol' tomato in Côte d'Ivoire and Burkina Faso (Fargette et al., 1996), on 'Guadajira' tomato in Cuba (Rodríguez et al., 2003) and 'Viradoro' tomato in Brazil (Guimarães et al., 2003).

The use of root-knot nematode resistance genes to manage *Meloidogyne* species in tomato and pepper production in Florida may provide another alternative to pre-plant fumigation with methyl bromide or other fumigants. However, depending on the extent of *M. mayaguensis*' distribution in the state, results of our study indicate that *M. mayaguensis* would most likely pose a disease problem where these root-knot nematode-resistant plant genotypes are deployed.

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