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Utility of *Mi* Gene Resistance in Tomato to Manage *Meloidogyne javanica* in North Florida[1]

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Abstract: Three field trials were conducted to determine response of *Meloidogyne javanica* to tomato cultivars containing the *Mi* gene for resistance in sequential tests. Trials were conducted in spring and fall 1997 and spring 1998 on the same site. Tomatoes were grown on polyethylene mulch at a site initially treated with methyl bromide and then infested with *M. javanica* via drip tubing. Cultivars with the *Mi* gene were 'PSR 8991994' and 'Sanibel', and susceptible cultivars were 'Colonial' and 'Agriset 761'. The resistant cultivars greatly suppressed root galling in the three tests. Population densities of second-stage juveniles also were low in soil samples collected from resistant cultivars. Tomato fruit yields were significantly increased in only one test when using resistant cultivars. However, the susceptible cultivars are high-yielding and recommended for north Florida production, while the cultivars containing the *Mi* gene are not as well adapted. In the three successive crops, no evidence of resistance-breaking biotypes of *M. javanica* was observed. With further incorporation into adapted cultivars, the *Mi* gene resistance could be a valuable tool to manage *M. javanica* in north Florida stake tomato production.

Key words: Lycopersicon esculentum, Meloidogyne javanica, Mi gene, nematode, resistance, root galling, root-knot nematode, tomato.

In Florida, fresh market stake tomatoes (*Lycopersicon esculentum* L.) are grown on approximately 15,000 ha each year with a value exceeding US $460 million (Anonymous, 1997). The production system used by Florida tomato growers includes methyl bromide soil fumigation, plastic mulch, and drip irrigation. This system produces yields that can exceed 60 MT/ha and has been in use for more than 30 years. A critical component of fresh market tomato production in Florida is application of methyl bromide to control soilborne pest problems including plant-parasitic nematodes. Methyl bromide, however, is scheduled for phaseout by the year 2005. Due to the successful use of this product over the past three decades in Florida, little research has been conducted on alternative nematode management techniques in stake-tomato production.

Plant-parasitic nematodes are major pests of field and vegetable crops in Florida, and *Meloidogyne* spp. are the most important plant parasites (Dunn and Noling, 1997). Resistance to one or more species of *Meloidogyne* is currently available in crops such as soybean and tobacco (Dunn and Noling, 1997; Roberts, 1992). *Mi* gene resistance in tomato, first reported by Smith (1944), has been used for more than 35 years and has proven useful for management of *M. arenaria, M. incognita,* and *M. javanica* (Roberts, 1992). The *Mi* gene has been incorporated into many commercially available tomato cultivars and is widely used as a root-knot nematode management technique in home gardens and processing tomato cultivars (Roberts and Thomason, 1989). The resistance conferred by this gene has some limitations such as presence of naturally occurring resistance-breaking biotypes (Roberts, 1992) and decreased resistance at high soil temperatures (Dropkin, 1969; Haroon et al., 1993). However, it is an effective tool in combination with other management techniques such as rotation and sanitation (Roberts, 1992).

Until recently, the *Mi* gene has not been incorporated into any horticulturally acceptable fresh market tomato cultivars nor tested in stake-tomato production systems in Florida. The extensive use of methyl bromide previously precluded the need for cultivars with this resistance. With the impending loss of methyl bromide, this resistance could become an important nematode management tool in Florida stake-tomato production.

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The objective of the study was to determine the effectiveness of *Mi* gene resistance in tomatoes for managing *M. javanica* in north Florida tomato production.

Materials and Methods

The test site was at the University of Florida, North Florida Research and Education Center, Quincy, Florida. The soil was a Dothan loamy fine sand (78% sand, 14% silt, 7% clay) that was moldboard-plowed and double-disced in early March 1997. Fertilizer was disc-incorporated in the 91-cm-wide bed area at the broadcast equivalent rate of 198-61-198 kg/ha of N-P_2O_5-K_2O. Prior to experiment initiation, methyl bromide (98%) was applied at a broadcast equivalent rate of 448 kg a.i./ha to the bed area. A 20-cm-deep application was made with a single row bed press through 3 chisels spaced 30 cm apart. Black polyethylene mulch (1.25-mil) and drip tubing were laid concurrently with methyl bromide application. Plot sizes were 2.54 m long and 0.91 m wide. Eighteen of the 36 plots were infested with *M. javanica*. A stock inoculum of eggs and second-stage infective juveniles (J2) was extracted from 'Rutgers' tomato roots with sodium hypochlorite (Hussey and Barker, 1973) and applied to plots through drip tubing on 12 April. Quantity of inoculum was calculated for 500 eggs and J2/100 cm^3 soil to a depth of 15 cm and width of 30 cm in each plot. Two days later, three stake-tomato transplants of resistant 'PSR 8991994' breeding line (PetoSeed Company, Saticoy, CA; 'Sanibel' sister line) and three of susceptible 'Colonial' were planted 51 cm apart into each plot.

Irrigation and foliar pest controls were applied as needed to promote good plant growth. Fruit was harvested from the inside two plants of the 'PSR 8991994' and 'Colonial' tomatoes in each plot on 20 June and 8 July. Root-gall ratings were made on these same plants in each plot on 11 July. Galling was estimated on a 0–10 scale where 0 = no root galling, 1 = 10%, 2 = 20%, 3 = 30%, 4 = 40%, 5 = 50%, 6 = 60%, 7 = 70%, 8 = 80%, 9 = 90%, and 10 = 100% of the root system galled. Five soil cores (2.54 cm diam., 20 cm deep) were collected separately around roots of resistant and susceptible plants in each plot. Soil was processed with a centrifugation-sugar flotation technique (Jenkins, 1964), and J2 were counted.

A test for fall tomato production was conducted in 1997 on the site of the spring trial. The previously placed drip tubing and plastic mulch were removed. Fertilizer (131-40-131 kg/ha of N-P_2O_5-K_2O) was applied manually to each bed and incorporated to 15 cm deep by rototilling. Bed pressing and shaping were conducted in the same operation. White-on-black polyethylene mulch (1.25-mil) and drip tubing were placed over the formed beds, but no methyl bromide was applied. 'Agriset 761' (susceptible) and 'Sanibel' (resistant) tomatoes were alternately planted on 22 August in each plot represented in the spring trial. From two plants of each cultivar, all tomato fruit, regardless of size, was harvested and weighed on 14 November. On 17 November, root galling was assessed on the same two plants each of 'Agriset 761' and 'Sanibel' in all plots.

A third test was conducted on the same site in spring 1998. Methods and materials were similar to the spring 1997 trial except that no methyl bromide was applied, and no nematode inoculum was added. Tomato cultivars used in this test were 'Sanibel' and 'Agriset 761'. Transplanting was on 10 April, and three harvests of mature fruit were made on 6 and 24 June and 1 July. Root-gall ratings were made as described above on 7 July.

In the three experiments, resistant (R) and susceptible (S) cultivars were planted into each plot according to the pattern SSSRRR (spring 1997), RSRSRS (fall 1997), and SSSRRR (spring 1998). Data in these tests were subjected to analysis of variance and their least significant difference values calculated (MSTAT-C, Michigan State University, East Lansing, MI). All differences listed in the results are at the $P \leq 0.05$ level.

Results

In the spring 1997 trial, no differences in tomato fruit weight, number of fruit, or

weight per fruit were found between the uninoculated 'PSR 8991994' or 'Colonial' tomatoes (Table 1). In spite of methyl bromide treatment, however, small residual populations of *M. javanica* were present in the uninoculated control treatment. The resistant 'PSR 8991994' showed less root galling and lower nematode numbers compared to the susceptible 'Colonial'. In plots where nematodes were added, 'PSR 8991994' had significantly increased fruit weight, number of fruit, weight per fruit, and exhibited low root galling and nematode populations as compared to 'Colonial'.

In the fall 1997 test, differences in total fruit weight were not found between 'Sanibel' and 'Agriset 761' where no nematodes had been added in the spring trial (Table 2). However, 'Sanibel' exhibited significantly lower root galling than 'Agriset 761'. In the plots that had been infested with nematodes in the spring, 'Agriset 761' yielded better than Sanibel although root galling was high. Root galling was again very limited in 'Sanibel'.

In the spring 1998 trial, no differences in fruit yield were found between 'Sanibel' and 'Agriset 761' in either the previously inoculated or uninoculated plots (Table 2). Root galling was lower in 'Sanibel' compared to 'Agriset 761' tomato in both treatments. Where nematodes were not added in the initial test (spring 1997), greater variability in the LSD value for root galling was apparent, and there was less variability in the data where nematodes had been previously added.

TABLE 2. Fruit yield and root galling in two field trials comparing the response of a resistant and susceptible stake tomato to *Meloidognye javanica*.

Cultivar[a]	Fruit weight (kg)[b]	Root galling[c]
Fall 1997		
Nematodes absent		
Agriset 761 (S)	5.0	4.2
Sanibel (R)	4.2	0.4
LSD ($P \leq 0.05$)	1.7	1.8
Nematodes present		
Agriset 761 (S)	7.2	7.1
Sanibel (R)	4.4	0.7
LSD ($P \leq 0.05$)	1.2	1.0
Spring 1998		
Nematodes absent		
Agriset 761 (S)	9.3	6.5
Sanibel (R)	9.4	0.1
LSD ($P \leq 0.05$)	2.8	4.9
Nematodes present		
Agriset 761 (S)	9.0	8.3
Sanibel (R)	9.1	0.1
LSD ($P \leq 0.05$)	3.2	1.6

[a] (R) = resistant, (S) = susceptible. Nematode status based on inoculation of 1997 crop with *Meloidogyne javanica*.

[b] All fruit was harvested on 14 November in the fall 1997 trial and on 6 and 24 June and 1 July in the spring 1998 test; values indicate means of two plants in each plot.

[c] Root galling was based on a 0–10 scale where 0 = no galling, 1 = 10%, 2 = 20%, 3 = 30%, 4 = 40%, 5 = 50%, 6 = 60%, 7 = 70%, 8 = 80%, 9 = 90%, and 10 = 100% of the root system galled.

Discussion

The cultivars PSR 8991994 and Sanibel exhibited good resistance to *M. javanica* in the three consecutive field trials. Additionally, root gall severity did not increase in the re-

TABLE 1. Yield, root-galling, and *Meloidogyne javanica* juvenile numbers in a field trial comparing the response of a resistant and susceptible stake tomato, spring 1997.

Cultivar or line[a]	Fruit weight (kg)[b]	Fruit number	Weight/ fruit (g)	Root galling[c]	Juveniles/ 100 cm^3 soil
No nematodes applied					
PSR 8991994 (R)	8.0	44	182	0.0	5
Colonial (S)	8.5	49	178	0.8	163
LSD ($P \leq 0.05$)	2.0	12	9	0.5	111
Nematodes applied					
PSR 8991994 (R)	10.5	56	191	0.1	132
Colonial (S)	7.1	40	176	7.0	4,523
LSD ($P \leq 0.05$)	1.8	9.3	9.0	0.8	2,810

[a] *Meloidogyne javanica* eggs and second-stage juveniles were applied via drip tubing at the rate of 0 or 500/100 cm^3 soil. (R) = resistant, (S) = susceptible.

[b] Fruit was harvested twice on 20 June and 8 July and graded to eliminate culls; values indicate means of two plants in each plot.

[c] Root galling was based on a 0–10 scale where 0 = no galling, 1 = 10%, 2 = 20%, 3 = 30%, 4 = 40%, 5 = 50%, 6 = 60%, 7 = 70%, 8 = 80%, 9 = 90%, and 10 = 100% of the root system galled.

sistant cultivars from one test to the next, indicating little to no presence of resistance-breaking biotypes. In these tests, *M. javanica* present in the field was derived from two sources. The inoculated *M. javanica* came from a tobacco field, while those that increased in the uninoculated treatment were remnants from previous tomato production at the site. By the third crop, nematodes in the uninoculated plots had increased to high levels under the susceptible tomato. Variability in galling LSD value probably reflects a spotty distribution in the native population at the site.

These tests did not show any loss of *Mi* gene effectiveness due to high soil temperatures (Dropkin, 1969; Haroon et al., 1993). Soil temperatures in the plots at 12-cm depth in early September ranged from 26 °C in the morning to a high of 31 °C in the afternoon. It is suspected that the combination of plastic mulch, daily watering, and plant canopy cover kept the soil temperature below that which would reduce effectiveness of the *Mi* gene. Further studies are needed to verify soil temperature influences on the *Mi* gene, especially since the fall tomato crop is planted during the highest-temperature months of July and August in north Florida.

Differences in tomato yield between the susceptible and resistant cultivars were variable among the three tests and probably related to cultivar. The susceptible cultivars, Agriset 761 and Colonial, are high-yielding and recommended for north Florida production (Maynard, 1994). The yield performance of 'PSR 8991994' or 'Sanibel', however, has not been documented in the region. Hence, comparisons in yield parameters could not be made directly concerning effects of *M. javanica* on these cultivars. With further incorporation of the *Mi* gene into adapted cultivars, more direct comparisons of the value of resistance on yield improvement can be made. Yield comparisons between isogeneic lines would provide even better information.

Experience from other tomato production systems indicates that *Mi* gene resistance is effective in reducing damage from several *Meloidogyne* spp. in tomato, but the resistance should be utilized in an IPM program context (Roberts and Thomason, 1989). Although continuous use has not resulted in major problems with resistant-breaking biotypes, sound IPM practices such as alternating susceptible and resistant cultivars in field production or utilizing good rotation systems would minimize this threat.

Further research is required to determine the effect of the *Mi* resistance gene in tomato on other populations of *M. javanica, M. incognita,* and *M. arenaria* that occur in northern Florida.

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