Journal of Nematology 18(3):353–359. 1986.

Meloidogyne incognita Resistance Characteristics in Tomato Genotypes Developed for Processing[1]

P. A. ROBERTS[2] AND D. MAY[3]

Abstract: Nine resistant processing tomato (*Lycopersicon esculentum*) cultivars and advanced lines were compared with four susceptible cultivars in 1,3-dichloropropene-fumigated and nontreated plots on *Meloidogyne incognita*-infested sites over 3 years. Yield of all resistant genotypes grown in nontreated and nematicide-treated plots did not differ and was greater than yield of susceptible genotypes. *M. incognita* initial soil population densities caused 39.3–56.5% significant ($P = 0.05$) yield suppressions of susceptible genotypes. Nematode injury to susceptible plants usually caused both fruit soluble solids content and pH to increase significantly ($P = 0.05$). Only trace nematode reproduction occurred on resistant genotypes in nontreated plots, whereas large population density increases occurred on susceptible genotypes. Slightly greater nematode reproduction occurred on resistant genotypes at the southern desert location, where soil temperature exceeded 30 C, than at other locations. At two locations resistant MOX 3076 supported greater reproduction than other resistant genotypes.

Key words: fruit quality, fruit yield, *Lycopersicon esculentum*, tomato, *Meloidogyne incognita*, root-knot nematode, population dynamics, resistance, soil fumigation, 1,3-dichloropropene.

Tomato (*Lycopersicon esculentum* L.) cultivars with the *Mi* gene for resistance to *Meloidogyne arenaria* (Neal) Chitwood, *M. incognita* (Kofoid and White) Chitwood, and *M. javanica* (Treub) Chitwood have been developed for machine harvesting; these tomatoes are used in processing or canning. California accounts for more than 80% of the United States processing tomato crop (12).

Root-knot nematode resistance in tomato is known to effectively limit nematode reproduction below 28–30 C (2,5, 9,11,13), but it does not confer immunity (5). The high yielding ability of resistant fresh market tomato cultivars grown in soil infested with *Meloidogyne* spp. is well known (8,9,14); however, the comparative effects of nematode infections on fruit quality characteristics of susceptible and resistant cultivars have not been studied (7). Our objectives were to evaluate the nematode resistance and fruit quality characteristics of processing tomato cultivars and advanced lines and to assess their usefulness as part of a nematode management system on *Meloidogyne*-infested land in California.

Received for publication 14 May 1985.

[1] This study was funded in part by the University of California Statewide Integrated Pest Management Project.

[2] Nematology Department, University of California, Riverside, CA 92521; stationed at the Kearney Agricultural Center, 9240 South Riverbend Ave., Parlier, CA 93648.

[3] Cooperative Extension Service, 1720 South Maple Ave., Fresno, CA 93702.

We thank W. C. Matthews, J. C. Wong, and M. S. Aguirre for technical help.

MATERIALS AND METHODS

Experiments were conducted over 3 years on sites naturally infested with *M. incognita* in Fresno County in California's San Joaquin Valley (Experiments 1, 3, 4, and 5) and in Riverside County in Southern California (Experiment 2). Soil types at the different locations were as follows: Experiment 1—sandy clay loam (55% sand, 17% silt, 28% clay). Experiment 2—sandy loam (61% sand, 23% silt, 16% clay). Experiment 3—sandy clay loam (60% sand, 18% silt, 22% clay). Experiment 4—sandy clay loam (60% sand, 18% silt, 22% clay). Experiment 5—sandy clay loam (51% sand, 23% silt, 26% clay). Tomato cultivars and lines evaluated in this study were obtained from private and University breeding programs. In each experiment the response of the *M. incognita*-resistant tomato cultivar was compared with that of a susceptible cultivar.

A split-block design was used in all experiments. Tomato entries were grown in randomized plots divided into fumigated and nontreated subplots. Each subplot was a single bed with two planted rows spaced 36 cm apart; beds were 1.68 m wide and 30.5 m long (Experiments 3, 4, and 5) or 15.3 m long (Experiment 1). Subplots were a single bed 76 cm wide and 15 m long with one planted row in Experiment 2. There were six replicates in Experiments 3 and 4 and four replicates in Experiments 1, 2, and 5.

Fumigant nematicide DD (1,3-dichloropropene : 1,2-dichloropropane mixture)

or Telone II (1,3-dichloropropene; 1,3-D) was applied at least 21 days before planting as follows: Experiment 1—93.5 liters/ha of 1,3-D applied with a MaClean handgun on a grid 30 cm × 30 cm, across the entire bed and 30 cm deep. Experiment 2—93.5 liters/ha of 1,3-D applied through one shank per bed and 30 cm deep. Experiment 3—121.5 liters/ha of 1,3-D applied through three shanks per bed and 30 cm deep. Experiment 4—101 liters/ha of 1,3-D applied through three shanks per bed and 30 cm deep. Experiment 5—140 liters/ha of DD applied through three shanks per bed and 30 cm deep. All plots were direct-seeded at 40 seeds per meter of row, and plant rows were thinned to give a stand density of 7–8 plants per meter of row.

Plots were mechanically harvested in Experiments 3 and 4 from a 29-m section of bed per subplot. A 10-kg subsample of unsorted fruit was removed from each subplot and divided into the ripeness categories of red, pink, or green and damage categories of sunburned and rotted. Individual fruit weight was determined on a sample of 25 fruit. Yield weights represented fruit in the red and pink categories. Experiments 1 and 2 were hand harvested from 3.5-m and 5.0-m sections of bed per subplot, respectively, and the fruit categorized as described above. Yield weights were based on fruit in the red and pink categories.

Fruit quality factors, pH, and percentage of soluble solids (°Brix) were determined on a hand-picked 2-kg sample of ripe (red category) fruit taken immediately before harvesting in Experiments 3 and 4. The fruit were washed and pureed, seeds and skins were discarded, and the puree was filtered to remove solids. The filtrate was used to measure pH and to determine °Brix using a Bausch and Lomb Abby refractometer at 20 C. Respective planting and harvesting dates were 22 February and 10 August (Experiment 1), 1 June and 21 September (Experiment 2), 11 April and 2 September (Experiment 3), 11 April and 9 August (Experiment 4), and 31 January and 30 July (Experiment 5).

Nematode population densities in soil at planting (Pi) and at harvest (Pf) were estimated from one soil sample composited from 12 cores, 2.5 cm × 40 cm deep, per bed in each subplot. Second-stage juveniles (J2) and eggs were extracted from 250 cm^3 soil by sieving through a 250-μm-pore sieve (to retain egg masses) and two 45-μm-pore sieves, with screenings from the latter sieves extracted for 3 days in a modified Baermann funnel-mist chamber. Egg masses retained on the 250-μm-pore sieve were processed in 1% NaOCl (6) to estimate numbers of eggs.

Eggs and J2 in roots at harvest were estimated by macerating in 1% NaOCl a 10-g subsample of chopped fresh roots from 15 root systems per subplot. Fifteen root systems per subplot were indexed for galling at harvest on a scale of 0 = no galls, 1 = 1–25%, 2 = 26–50%, 3 = 51–75%, and 4 = 76–100% galled.

Results

Initial soil nematode population densities: The Pi (J2 and eggs/250 cm^3 soil) values for nematicide treated and nontreated plots, respectively, were as follows: Experiment 1—treated mean 65 (range 0–203), nontreated mean 307 (range 88–722). Experiment 2—treated 0.3 (0–1), nontreated 98 (45–140). Experiment 3—treated 2 (0–34), nontreated 79 (17–198). Experiment 4—treated 0.6 (0–6), nontreated 259 (14–1,013). Experiment 5—treated 6 (0–42), nontreated 165 (8–568). Except in Experiment 1 where the Pi of treated subplots were high, the low Pi of treated subplots compared with nontreated subplots provided ideal conditions to evaluate the performance of tomato plants with minimal *M. incognita* damage.

Yield responses: There were no differences in yields among resistant tomato cultivars and advanced lines grown in nontreated and treated plots in any experiment (Table 1). In Experiments 2–4 significant yield increases in response to fumigation occurred in the susceptible but not in the resistant entries.

In Experiment 1 nematicide treatment did not adequately reduce the Pi. There were no differences in yields among treated and nontreated plots (Table 1). Susceptible plants were heavily infected in both treated and nontreated plots, whereas resistant plants were only lightly infected (Table 2). Although lower, mean yields of

TABLE 1. Fruit yields of *Meloidogyne* susceptible and resistant tomatoes grown in nematicide treated and nontreated field plots in four experiments.

Experiment	Entry	Nematode reaction†	Yield (MT/ha)		Tolerance rating§
			Treated	Nontreated	
1 (1982)	UC 82	S	96.7	79.1	81.8
	MURIETTA	S	89.9	93.9	104.4
	XPH 671	R	100.4	102.4	102.0
	GS 27	R	121.5	133.8	110.1
	Hy 9889	R	131.6	132.3	100.5
	LSD ($P = 0.05$)		NS‡		
2 (1983)	UC 82	S	42.7	20.3*	47.5
	XPH 5041	S	34.9	21.2*	60.7
	XPH 671	R	25.0	25.8	103.2
	GS 27	R	41.1	44.2	107.5
	Hy 9889	R	25.4	22.5	88.6
	CX 8202	R	32.2	23.7	73.6
	MOX 3076	R	38.3	39.1	102.1
	MOX 3078	R	40.5	39.2	96.8
	LSD ($P = 0.05$)		11.83		
3 (1983)	UC 82	S	97.7	50.7*	51.8
	XPH 5041	S	73.3	30.9*	45.0
	GS 27	R	103.9	109.7	110.0
	Hy 9889	R	87.4	90.9	104.6
	CX 8202	R	88.1	85.4	98.5
	MOX 3076	R	91.6	86.6	95.3
	LSD ($P = 0.05$)		22.26		
4 (1984)	UC 82	S	88.5	38.6*	43.5
	NS 201	S	59.4	26.4*	44.5
	GS 27	R	76.6	80.2	104.7
	Hy 9889	R	45.5	48.2	105.9
	CX 8202	R	54.4	57.8	106.3
	MOX 3076	R	49.0	46.0	94.0
	MOX 3078	R	52.1	50.1	96.1
	H 2476	R	40.7	44.6	109.5
	P 1200	R	53.3	65.5	122.8
	P 1400	R	55.1	58.5	106.2
	LSD ($P = 0.05$)		12.56		

* The difference between the values in nematicide and no-nematicide treatments for that entry is significant ($P = 0.05$).
† S = susceptible. R = resistant.
‡ Not significant for interaction (nematicide application–tomato entry).
§ Nontreated yield/treated yield × 100.

the susceptible entries were not significantly different from yields of resistant entries (Table 1).

Fruit yield components: There were no differences in ripeness among susceptible and resistant tomato fruit from Experiments 3 and 4 for the entry–nematicide interaction. There were no significant differences in sunburn damage to fruit, even though greater exposure of fruit occurred on susceptible plants in nontreated plots in late season because of collapse and death of the vines. The entry–nematicide interaction was not significant for percentage of fruit culled because of rotting and cracking.

Fruit quality: The interaction of entry–nematicide for fruit pH was significant ($P = 0.05$) in Experiments 3 and 4. In Experiment 3, pH of susceptible UC 82 and XPH 5041 was significantly higher in nontreated plots (4.52 and 4.64, respectively) than in treated plots (4.45 and 4.52, respectively). The fruit pH of resistant entries did not differ between treated and nontreated plots, but fruit pH of all resistant entries was significantly higher than that of UC 82 in treated plots.

In Experiment 4 the fruit soluble solids content was significantly ($P = 0.05$) greater in susceptible UC 82 and NS 201 in nontreated plots (4.57 and 4.83, respectively) than in treated plots (4.15 and 4.47,

TABLE 2. *Meloidogyne incognita* egg and second-stage juvenile numbers in roots and root gall indices at harvest for root systems of susceptible and resistant tomatoes grown in nematicide treated and nontreated field plots in five experiments.

Experiment	Entry	Nematode reaction†	Eggs + J2/g fresh root		Gall index	
			Treated	Nontreated	Treated	Nontreated
1 (1982)	UC 82	S	1,976	6,536*	1.9	2.9*
	MURIETTA	S	5,072	4,657	1.5	2.3
	XPH 671	R	< 1	0	0.1	0.3
	GS 27	R	3	1	0.1	0.4
	Hy 9889	R	1	53	0.1	0.7
	LSD‡ ($P = 0.05$)		4,171.5		0.82	
2 (1983)	UC82	S	2,886	9,299*	1.1	3.6*
	XPH 5041	S	4,800	3,189	0.4	3.8*
	XPH 671	R	32	1,638	0	0.7
	GS 27	R	18	655	< 0.1	0.1
	Hy 9889	R	71	179	0	0.1
	CX 8202	R	1,210	477	0.1	0.2
	MOX 3076	R	41	3,015*	0	0.2
	MOX 3078	R	14	85	0	0
	LSD ($P = 0.05$)		2,370.9		0.40	
3 (1983)	UC 82	S	3	6,141*	0.1	3.1*
	XPH 5041	S	1	8,259*	0	3.1*
	GS 27	R	1	8	0	0.1
	Hy 9889	R	2	1	0	0.1
	CX 8202	R	2	1	0	0.3
	MOX 3076	R	0	3	0	0.3
	LSD ($P = 0.05$)		2,657.0		0.36	
4 (1984)	UC 82	S	25	11,866*	0.2	3.0*
	NS 201	S	93	11,541*	0.2	2.9*
	GS 27	R	< 1	67	< 0.1	0.1
	Hy 9889	R	0	15	0	0.1
	CX 8202	R	0	140	0	0.2
	MOX 3076	R	0	696	0.1	0.2
	MOX 3078	R	0	0	0	0
	H 2476	R	< 1	< 1	0	< 0.1
	P 1200	R	0	3	< 0.1	0.1
	P 1400	R	< 1	13	0	0.1
	LSD ($P = 0.05$)		1,777.4		0.23	
5 (1984)	UC 82	S	43	3,211*	0.2	2.3*
	GS 27	R	< 1	83	0	< 0.1
	Hy 9889	R	< 1	4	0	< 0.1
	CX 8202	R	0	9	0	< 0.1
	MOX 3076	R	0	< 1	0	0
	MOX 3078	R	2	0	0	< 0.1
	H 2476	R	< 1	0	0	0
	LSD ($P = 0.05$)		634.9		0.19	

* The difference between the values in nematicide and no-nematicide treatments for that entry is significant ($P = 0.05$).
† S = susceptible. R = resistant.
‡ LSD for interaction (nematicide application–tomato entry).

respectively). Except for resistant P 1200, the resistant entries did not show significant differences in soluble solids content between nontreated and treated plots.

Nematode infection and reproduction on roots: In Experiments 3–5 the entry–nematicide interaction was significant for numbers of eggs and J2 per gram of root and for gall indices. Root galling and reproduction were nondetectable or very low on all resistant entries in treated and nontreated plots, with no significant interaction. Susceptible entries had significantly greater infection in nontreated compared with treated plots in all of these experiments. Similar results were obtained in Experiments 1 and 2, except for greater infection of susceptible entries in treated plots of Experiment 1

TABLE 3. *Meloidogyne incognita* populations in soil at harvest and Pf/Pi ratios for *Meloidogyne* susceptible and resistant tomatoes grown in nematicide treated and nontreated field plots in five experiments.

Experiment	Entry	Nematode reaction†	Eggs + J2/250 cm³ soil (Pf)		Pf/Pi ratio in soil (nontreated)
			Treated	Nontreated	
1 (1982)	UC 82	S	1,354	733	1.9
	MURIETTA	S	488	735	2.3
	XPH 671	R	17	87	0.5
	GS 27	R	14	47	0.3
	Hy 9889	R	27	179	0.8
	LSD ($P = 0.05$)		NS‡		1.3
2 (1983)	UC 82	S	1,212	2,371*	50.5
	XPH 5041	S	419	2,808*	43.8
	XPH 671	R	6	419	5.1
	GS 27	R	< 1	52	0.5
	Hy 9889	R	< 1	6	0.1
	CX 8202	R	13	74	1.1
	MOX 3076	R	0	54	0.8
	MOX 3078	R	1	12	0.2
	LSD ($P = 0.05$)		1,047		34.8
3 (1983)	UC 82	S	8	466	7.4
	XPH 5041	S	4	1,235*	18.8
	GS 27	R	0	10	0.4
	Hy 9889	R	1	3	0.1
	CX 8202	R	5	37	0.4
	MOX 3076	R	1	0	0
	LSD ($P = 0.05$)		581		10.0
4 (1984)	UC 82	S	100	17,695*	169.1
	NS 201	S	82	9,273*	74.5
	GS 27	R	0	62	0.2
	Hy 9889	R	3	19	< 0.1
	CX 8202	R	7	28	0.3
	MOX 3076	R	7	1,869	16.2
	MOX 3078	R	0	2	< 0.1
	H 2476	R	11	112	0.6
	P 1200	R	5	64	0.6
	P 1400	R	0	14	0.2
	LSD ($P = 0.05$)		4,447		62.0
5 (1984)	UC 82	S	368	10,989*	375.3
	GS 27	R	17	160	0.2
	Hy 9889	R	180	121	0.6
	CX 8202	R	1	211	0.8
	MOX 3076	R	0	2,631	14.5
	MOX 3078	R	0	254	4.0
	H 2476	R	0	26	0.3
	LSD ($P = 0.05$)		3,630		NS‡

* The difference between the values in nematicide and no-nematicide treatments for that entry is significant ($P = 0.05$).
† S = susceptible. R = resistant.
‡ Not significant for interaction (nematicide application–tomato entry); or not significant for Pf/Pi ratio between entries.

and greater infection of resistant entries in treated plots of Experiment 2.

Final soil nematode population densities: Egg and J2 Pf in the soil (Table 3) showed the same trends as Pf in roots at harvest (Table 2). In nontreated plots low infection and reproduction on most resistant entries resulted in low Pf values and soil Pf/Pi ratios < 1.0, except for resistant MOX 3076 in Experiments 4 and 5. Soil Pf/Pi values for susceptible entries were high, ranging from 1.9 to 375.3 (Table 3).

DISCUSSION

Growing susceptible and resistant tomato entries on infested and noninfested (nematicide treated) plots provides conditions to compare performance of the entries in the field. The efficacy of the fumigant nematicide treatment was excellent in Ex-

periments 2–5, but poor in Experiment 1. The handgun application of fumigant and the higher soil clay fraction may have reduced fumigant efficacy in Experiment 1.

Resistant tomato genotypes were not adversely affected by *M. incognita* at different localities and in different years. The good performance of resistant tomato entries under these conditions was shown in Experiments 2–4 in which the yield of these entries was not suppressed by population densities that induced 39–57% yield suppression of susceptible cultivars.

The yield performance of these resistant tomato genotypes in *M. incognita*-infested soil demonstrated that they can be grown without use of additional nematode management practices. In addition, yield suppression of 40–60% in susceptible processing tomatoes is not commonly observed; tomatoes are not often subjected to such damaging population densities (1,4). Our results support findings of good yield performance of tomato cultivars and lines with the *Mi* gene (14).

The desirable fruit processing quality traits of high soluble solids content and low pH were affected by nematode injury in susceptible but not in resistant genotypes. Solids and pH were increased in fruit from nematode-infected susceptible plants. These changes are similar to the increase in solids and pH in fruit of tomato plants stressed by water deficit (10), suggesting that nematode effects on fruit quality may be caused by alteration of plant water status. An increase in solids content of fruit from infected plants would partly offset the economic loss of total fruit weight reduction by increasing the processed paste-yield per weight of fruit. However, the increase in pH is an undesirable result of nematode injury.

M. incognita reproduced more on resistant MOX 3076 than on other resistant genotypes in two experiments. This variation could result from variation of *M. incognita* populations in ability to develop on resistant tomato genotypes (3,9,15); however, the other resistant entries, which also possess the *Mi* gene, did not respond similarly. High soil temperature (> 30 C) occurred in Experiment 2 in the southern California location which may account for population increases on resistant plants due to some resistance breakdown at these temperatures (2,3).

To minimize the possibility of selecting nematodes virulent to resistant plants, it is important not to monoculture these resistant cultivars. The low Pf following resistant cultivars in infested plots suggest that resistant processing tomatoes may be useful in rotations.

Literature Cited

1. Barker, K. R., P. B. Shoemaker, and L. A. Nelson. 1976. Relationships of initial population densities of *Meloidogyne incognita* and *M. hapla* to yield of tomato. Journal of Nematology 8:232–239.

2. Dropkin, V. H. 1969. The necrotic reaction of tomatoes and other hosts resistant to *Meloidogyne*: Reversal by temperature. Phytopathology 59:1632–1637.

3. Fassuliotis, G. 1979. Plant breeding for root-knot nematode resistance. Pp. 425–453 *in* F. Lamberti and C. E. Taylor, eds. Root-knot nematodes (*Meloidogyne* species) systematics, biology and control. New York: Academic Press.

4. Ferris, H. 1984. Nematode damage functions: The problems of experimental and sampling error. Journal of Nematology 16:1–9.

5. Hadisoeganda, W. W., and J. N. Sasser. 1982. Resistance of tomato, bean, southern pea, and garden pea cultivars to root-knot nematodes based on host suitability. Plant Disease 66:145–150.

6. Hussey, R. S., and K. R. Barker. 1973. A comparison of methods of collecting inocula of *Meloidogyne* spp., including a new technique. Plant Disease Reporter 57:1025–1028.

7. Medina-Filho, H. P., and M. A. Stevens. 1980. Tomato breeding for nematode resistance: Survey of resistant varieties for horticultural characteristics and genotype of acid phosphatase. Acta Horticulture 100: 383–393.

8. Netscher, C., and J. C. Mauboussin. 1973. Resultats d'un essai concernant l'efficacite comparee d'une variete de tomate resistante et de certains nematicides contre *Meloidogyne javanica*. Cahier ORSTOM, series Biologie 11:97–102.

9. Prot, J.-C. 1984. A naturally occurring resistance breaking biotype of *Meloidogyne arenaria* on tomato. Reproduction and pathogenicity on tomato cultivars Roma and Rossol. Revue de Nematologie 7: 23–28.

10. Rendon-Poblete, E. 1980. Effect of soil water status on yield, quality and root development of several tomato genotypes. Ph.D. thesis, University of California, Davis.

11. Riggs, R. D., and N. N. Winstead. 1959. Studies on resistance in tomato to root knot nematodes and on the occurrence of pathogenic biotypes. Phytopathology 49:716–724.

12. Roberts, P. A. 1982. Plant resistance in nematode pest management. Journal of Nematology 14: 24–33.

13. Sikora, R. A., K. Sitaramaiah, and R. S. Singh.

1973. Reaction of root-knot nematode-resistant tomato cultivars to *Meloidogyne javanica* in India. Plant Disease Reporter 57:141–143.

14. Southards, C. J. 1973. A field evaluation of nematode-resistant tomato varieties for vine-ripe tomato production. Tennessee Farm and Home Science 85:18–20.

15. Viglierchio, D. R. 1978. Resistant host responses to ten California populations of *Meloidogyne incognita*. Journal of Nematology 10:224–227.