J. Amer. Soc. Hort. Sci. 122(2):200–204. 1997.

Effectiveness of Resistance to Southern Root-knot Nematode in 'Carolina Cayenne' Pepper in Greenhouse, Microplot, and Field Tests

J.A. Thies
U.S. Vegetable Laboratory, Agricultural Research Service, U.S. Department of Agriculture, 2875 Savannah Highway, Charleston, SC 29414

J.D. Mueller
Department of Plant Pathology and Physiology, Edisto Research and Education Center, Clemson University, P.O. Box 247, Blackville, SC 29817

R.L. Fery
U.S. Vegetable Laboratory, Agricultural Research Service, U.S. Department of Agriculture, 2875 Savannah Highway, Charleston, SC 29414

Additional index words. chili, host plant resistance, *Meloidogyne incognita*, *Capsicum annuum*

Abstract. **The southern root-knot nematode [*Meloidogyne incognita* (Kofoid & White) Chitwood] is a serious pest of pepper (*Capsicum annuum* L.). Currently, methyl bromide is used for nematode control, but the pending withdrawal of this fumigant from the United States market has resulted in a need for effective alternative root-knot nematode management measures. We evaluated the effectiveness of resistance of 'Carolina Cayenne' relative to the susceptible genotypes 'Early Calwonder' and PA-136 in greenhouse, microplot, and field studies. In all tests, 'Carolina Cayenne' exhibited exceptionally high resistance (minimal galling, minimal nematode reproduction, and no yield reduction) to *M. incognita*; 'Early Calwonder' and PA-136 were highly susceptible. In a test conducted in a heavily infested field, 'Carolina Cayenne' outyielded PA-136 by 339%. The exceptionally high resistance exhibited by 'Carolina Cayenne' provides an alternative to methyl bromide and other fumigant nematicides for managing root-knot nematodes in pepper.**

The southern root-knot nematode (*Meloidogyne incognita*) is a major pest of pepper (*Capsicum annuum*), causing severe yield losses worldwide (Di Vito et al., 1985; Fery and Dukes, 1984; Lamberti, 1979; Sasser and Freckman, 1987; Zamora et al., 1994). In microplot studies, *M. incognita* suppressed yield of hot peppers in New Mexico (Lindsey and Clayshulte, 1982; Thomas and Cardenas, 1985) and sweet peppers in Italy (Di Vito et al., 1985 and 1992). Soil fumigants have been used to control root-knot nematodes in many high-value vegetable crops, including peppers [U.S. Department of Agriculture (USDA), 1993]. However, the U.S. Clean Air Act (Section 602) mandates that methyl bromide, the leading fumigant used in pepper culture, be withdrawn from production, importation, and use in the United States by the year 2000 (USDA, 1993). Plant resistance, if available, would be an economically and environmentally safe alternative to fumigants for controlling root-knot nematodes in pepper.

Resistance in pepper to root-knot nematodes has been identified in several *Capsicum* germplasm sources, including *C. annuum*, *C. chacoense* L., *C. chinense* L., and *C. frutescens* L. (Di Vito et al., 1992, 1993a, 1993b; Hare, 1957; Hendy et al., 1985a, 1985b; Martin and Crawford, 1958). However, few resistant *C. annuum* cultivars have been developed. 'Carolina Cayenne' is a cayenne pepper that is resistant to *M. incognita* races 1–4 and *M. arenaria* (Fery et al., 1986; Noe, 1992; Zamora et al. 1994). This paper reports the results of greenhouse, microplot, and field studies designed to characterize the effectiveness of 'Carolina Cayenne' resistance to the southern root-knot nematode relative to known susceptible pepper genotypes 'Early Calwonder' and PA-136.

Materials and Methods

Greenhouse and field studies were conducted at the U.S. Vegetable Laboratory, Charleston, S.C.; microplot and field studies were conducted at the Clemson Univ. Edisto Research and Education Center, Blackville, S.C. Egg inocula for all tests were extracted from roots of cowpea [*Vigna unguiculata* (L.) Walp.] or pepper plants infected with *M. incognita* race 3 using 0.5% NaOCl (Hussey and Barker, 1973). The pepper genotypes used in the tests were 'Carolina Cayenne', 'Early Calwonder', and PA-136. 'Carolina Cayenne' is highly resistant to *M. incognita,* and PA-136 and 'Early Calwonder' are susceptible (unpublished data). 'Carolina Cayenne' and PA-136 are quite similar in plant habit and yield characteristics; both genotypes were selected from a 'Carolina Hot' population that was heterogeneous for resistance to *M. incognita* (Fery et al., 1986; Fery and Dukes, 1996).

Greenhouse experiment. A greenhouse experiment was conducted to determine the reaction of 'Carolina Cayenne', PA-136, and 'Early Calwonder' to *M. incognita* race 3 at inoculum levels of 0, 3000, or 6000 eggs per plant. The experimental design was a randomized complete block replicated six times with treatments in a split-plot arrangement. Whole plots were three nematode inoculum levels and subplots were three pepper genotypes. Each subplot consisted of four pots (one plant per pot).

Seedlings of each genotype were started in 25 × 51 × 4.5-cm-deep plastic flats containing Jiffy Mix (Jiffy Products of America,

Received for publication 1 Apr. 1996. Accepted for publication 14 Nov. 1996. Contribution no. 4188 of the Clemson Univ. Dept. of Plant Pathology and Physiology. This work was supported in part by the South Carolina Agricultural Experiment Station and by the Integrated Pest Management Collaborative Research Support Program, U.S. Agency for International Development under grant no. LAG-4196-G-00-3053-00. Use of trade names does not imply endorsement by the USDA. The cost of publishing this paper was defrayed in part by the payment of page charges. Under postal regulations, this paper therefore must be hereby marked *advertisement* solely to indicate this fact.

Inc., Batavia, Ill.) potting mix. The flats were placed on heating pads that maintained the temperature of the planting medium at 28 °C. Ten-day-old seedlings of uniform size were transplanted into 1125-mL clay pots containing a steam-pasteurized mixture of 2 sand : 1 soil (by volume). Fourteen days after transplanting to pots, 5 mL tap water containing 0, 3000, or 6000 *M. incognita* race 3 eggs were pipetted around the base of each plant. Plants were fertilized weekly with an aqueous solution of 10N–10P–10K soluble fertilizer. The greenhouse temperature was maintained at 23 to 29 °C.

Twelve weeks after inoculation, fruit were harvested, counted, and weighed. The entire root system was carefully removed from each pot, washed, and weighed. Egg masses were stained by submerging the entire root system in 0.1% phloxine B for 15 min. Then, roots were rinsed with tap water and each root system was scored for galling and egg mass production using a 1 to 9 scale as follows: 1 = no galls or egg masses present, 2 = 1% to 3% roots galled or covered with egg masses, 3 = 4% to 10%, 4 = 11% to 25%, 5 = 26% to 35%, 6 = 36% to 50%, 7 = 51% to 65%, 8 = 66% to 80%, and 9 = >80%. Fibrous roots were clipped from the plant, cut into 1- to 2-cm pieces, and eggs were extracted from a 10-g sample of roots using 1% NaOCl (Hussey and Barker, 1973). Eggs were counted using a stereomicroscope.

Microplot experiment. A microplot experiment was conducted at Blackville, S.C., to compare the severity of root galling, nematode reproduction, and fruit yield of 'Carolina Cayenne', PA-136, and 'Early Calwonder' plants inoculated with 0, 6000, or 12000 *M. incognita* race 3 eggs per plant. The experimental design was a randomized complete block with 12 replications. Each of the 57-cm-diameter microplots was fumigated with 151 g of a combination of (w/w) 98% methyl bromide (CH_3Br) and 2% chloropicrin (CCl_3NO_2) on 13 May 1994.

Three seeds of each pepper genotype were planted in plastic growing trays containing 40 individual 5.5 × 5.5 × 7.0-cm deep plastic cells (Growing Systems Inc., Milwaukee, Wis.) filled with Jiffy Mix. The growing trays were placed on heating pads that maintained the temperature of the planting medium at 26 °C. One week after emergence, seedlings were thinned to one per cell and maintained in a greenhouse at 23 to 29 °C. On 21 June 1994, a single 6-week-old seedling was transplanted into each microplot and 10 mL of tap water containing 0, 3000, or 6000 *M. incognita* eggs was pipetted around the base of each plant. Each plant was inoculated again on 29 June 1994 using the same procedure with the same inoculum levels. Final inoculum levels were 0, 6000, or 12000 eggs per plant. The plots were hand-weeded and fertilized with 10N–10P–10K fertilizer as needed.

Fruit were harvested on 9 Sept., 5 Oct., and 19 Oct. 1994. Fruit weights were recorded at each harvest. Six cores (2.5 cm in diameter) of soil were taken to a 20-cm depth in the root zone of each plant on 21 July (midseason samples) and 19 Oct. 1994 (harvest samples). Juveniles were extracted from 400 cm^3 soil using the sugar flotation method (Jenkins, 1964). Eggs were extracted from root fragments present in the 400-cm^3 soil sample using 1% NaOCl (Hussey and Barker, 1973). Eggs and juveniles were counted in the respective samples using a stereomicroscope.

All plants were dug on 2 Nov. 1994. Shoots were cut at the base of the stem and removed. The entire root system of each plant was carefully washed, blotted dry, and weighed. Each root system was scored for galling and egg production using a 1 to 9 scale and eggs were extracted from 10 g fibrous roots and counted as described above.

Field expt. I. A field experiment was conducted at Charleston, S.C., to compare the severity of root galling, nematode reproduction, and fruit yield of 'Carolina Cayenne', PA-136, and 'Early Calwonder' plants inoculated with 0, 6000, or 12000 *M. incognita* race 3 eggs per plant. The field was fumigated with (w/w) 98% CH_3Br : 2% CCl_3NO_2 on 31 May 1994. The soil fertility was adjusted according to Clemson Univ. soil test recommendations. The experimental design was a randomized block with six replications. Experimental plots were three row beds established on 1-m centers with 46-cm in-row plant spacing and 15 plants per row.

Seeds of each pepper genotype were planted on 23 Apr. 1994 as described above for the greenhouse experiment. Single seedlings were transplanted into 4-cm-diameter Jiffy Pellets (Jiffy Products of America, Inc.) on 6 and 7 May 1994 and maintained in the greenhouse at 23 to 29 °C. Four weeks later, the seedlings were moved outdoors to harden off. Due to heavy rainfall during June and July, transplanting was delayed until 20 July 1994. Ten milliliters tap water containing 0, 3000, or 6000 *M. incognita* race 3 eggs was pipetted around the base of each pepper seedling at transplanting. On 3 Aug. 1994, 63 mL of tap water containing 0, 3000, or 6000 *M. incognita* eggs was poured into three 5-cm-deep holes around the base of the plant (according to previously assigned treatments). Final inoculum levels were 0, 6000, or 12000 eggs per plant.

All harvest data and nematode data were collected from the entire center row of each plot. Mature green bell peppers were harvested weekly from 6 Sept. to 7 Oct. 1994. Cayenne peppers were harvested weekly as mature red fruit from 17 Oct. to 7 Nov. 1994. On 18 Oct. 1994, 10 cores of soil were collected in the root zones of pepper plants from the center row of each plot and juveniles were extracted as previously described. Root systems of 'Early Calwonder' were dug on 3 Nov. 1994; root systems of 'Carolina Cayenne' and PA-136 were dug 23 Nov. 1994. Each root system was scored for galling and egg mass production. Eggs were extracted from a 20-g subsample of roots and counted as stated above.

Field expt. II. In 1994, an experiment was conducted at Blackville, S.C., to compare the severity of root galling, nematode reproduction, and fruit yield of 'Carolina Cayenne' and PA-136 in a field infested with *M. incognita* race 3. The field was infested with *M. incognita* in 1993 by inoculating a PA-136 planting with about 7000 eggs of *M. incognita* race 3 per plant. A winter cover crop of hairy vetch (*Vicia villosa* Roth) was sown over the pepper plants on 3 Dec. 1993 to maintain the *M. incognita* populations over the winter. The hairy vetch was plowed down on 10 May 1994. The roots of the hairy vetch plants had large numbers of galls and egg masses at plowdown, indicating the presence of a high population of *M. incognita*. Plots were nine row beds established on 1-m centers with 46-cm in-row plant spacing and 15 plants per row. The experimental design was a randomized block with nine replications.

Seeds of 'Carolina Cayenne' and PA-136 were planted on 18 to 20 Apr. 1994 in flats, as described for the greenhouse experiment. Pepper seedlings were transplanted into Jiffy Pellets from 29 Apr. to 3 May 1994 and maintained in the greenhouse at 23 to 29 °C. Pepper seedlings were moved outdoors to harden on 25 May 1994. The herbicide metolachlor [2-chloro-*N*-(2-ethyl-6-methylphenyl)-*N*-(2-methoxy-1-methylethyl)acetamide] was sprayed on the soil on 1 June 1994 at 2.2 $kg \cdot ha^{-1}$ (a.i.) and preplant incorporated. The soil fertility was adjusted according to Clemson Univ. soil test recommendations. The peppers were transplanted into the field on 2 June 1994. On 26 July and 19 Oct. 1994, 10 cores of soil were collected in the root zones of pepper plants from rows two, five, and eight of each nine-row plot; juveniles and eggs were extracted from each sample as described above for the microplot experi-

Table 1. Comparison of three pepper genotypes differing in resistance to southern root-knot nematode for gall index, egg mass index, numbers of *Meloidogyne incognita* eggs, and fruit weight, 12 weeks after inoculation with *M. incognita*, greenhouse experiment.

Pepper genotype/ inoculum level[z]	Gall index[y]	Egg mass index[x]	No. eggs/g fresh root	Fruit yield (g/plant)
Carolina Cayenne				
0	1.0 b[w]	1.0 b	289 c	48.0 a[v]
3000	1.6 b	1.5 b	139 c	46.1 a
6000	1.7 b	1.5 b	1764 c	51.2 a
PA-136				
0	1.0 b	1.0 b	493 c	60.3 a
3000	8.9 a	8.9 a	229176 a	30.9 a
6000	8.7 a	8.7 a	224210 a	31.0 a
Early Calwonder				
0	1.0 b	1.0 b	229 c	75.7 a
3000	8.5 a	8.5 a	177119 ab	45.7 b
6000	8.5 a	8.6 a	136357 b	38.7 b

[z]Each 24-day-old plant was inoculated with 0, 3000, or 6000 *M. incognita* eggs.
[y]Gall index: 1 = no galling; 9 = >80% of root system galled.
[x]Egg mass index: 1 = no egg masses; 9 = >80% of root system covered with egg masses.
[w]Means in a column followed by the same letters are not significantly different according to Duncan's multiple range test ($P<0.05$).
[v]Separate mean comparisons apply to cayenne pepper ('Carolina Cayenne' and PA-136) fruit yields and bell pepper ('Early Calwonder') fruit yields.

ment. Mature red fruit were harvested from five plants in rows two, five, and eight of each plot on 9 Sept., 5 Oct., and 19 Oct. 1994. On 19 Oct. 1994, five plants were dug from rows one, three, four, six, seven, and nine of each plot. The entire root system of each plant was washed, each root system was scored for galling and egg production, and eggs were extracted from a 10-g subsample of roots, and counted as stated above.

Statistical analysis. Data from all experiments were subjected to analysis of variance using SAS (SAS Institute, Cary, N.C.) and means were separated using Duncan's multiple range test. Yield data for cayenne peppers ('Carolina Cayenne' and PA-136) and bell pepper ('Early Calwonder') were analyzed separately.

Results

Greenhouse experiment. 'Carolina Cayenne' exhibited exceptionally high resistance to *M. incognita* race 3 in the greenhouse experiment, i.e., minimal nematode reproduction, minimal galling, and no yield reduction (Table 1). For example, 'Carolina Cayenne' produced 99.9% fewer eggs than PA-136 and 'Early Calwonder' at the 3000-egg inoculum level, and 99.2% and 98.7% fewer eggs than PA-136 and 'Early Calwonder', respectively, at the 6000-egg inoculum level. 'Early Calwonder' and PA-136 were susceptible; roots of both genotypes were severely galled at the 3000- and 6000-egg inoculum levels. Fruit yield of 'Early Calwonder' plants inoculated with 6000 eggs was only one-half of that of uninoculated control plants ($P < 0.05$). Fruit yields of inoculated PA-136 plants were reduced by about 50% compared to uninoculated control plants. Differences were not detected in root galling, egg production, and fruit yields within the individual pepper genotypes between the 3000- and 6000-egg inoculum levels. However, there was a significant ($P < 0.01$) cultivar × egg inoculum level interaction for gall and egg mass indices, and eggs per gram fresh root.

Microplot experiment. 'Carolina Cayenne' exhibited exceptionally high resistance to *M. incognita*, i.e., no galls or egg masses were visible on the roots, nematode reproduction was very low, and fruit yield was not reduced in infested microplots (Table 2). PA-136 and 'Early Calwonder' exhibited susceptible reactions for root galling and nematode reproduction. Fruit yield of inoculated PA-136 plants was reduced ($P<0.10$) compared to the uninoculated control. Fruit yield of PA-136 plants inoculated with 6000 eggs was reduced compared to fruit yield of the related line, 'Carolina Cayenne', at all inoculum levels.

At midseason, soil samples collected from plots where 'Carolina Cayenne' plants had been inoculated with 6000 eggs per plant had 90.3% and 85.1% fewer eggs and juveniles ($P < 0.05$) than soil samples from PA-136 and 'Early Calwonder', respectively (Table 2). Soil samples from 'Carolina Cayenne' plots inoculated with 12000 eggs per plant had 99.4% and 99.3% fewer eggs and juveniles ($P < 0.05$) than samples collected from PA-136 and 'Early Calwonder' plots. At harvest, numbers of eggs and juveniles in soil samples collected from plots where 'Carolina Cayenne' plants had been inoculated with either 6000 or 12000 eggs per plant were about 99% less ($P < 0.05$) than samples collected from comparable PA-136 and 'Early Calwonder' plots. 'Carolina Cayenne' plants inoculated with either 6000 or 12000 eggs per plant supported <1% of the *M. incognita* reproduction of either PA-136 or 'Early Calwonder'. PA-136 plants inoculated with 6000 eggs per plant had greater ($P < 0.05$) numbers of eggs per gram fresh root than 'Early Calwonder' plants inoculated with the same number of eggs. Fruit yield of PA-136 plants was less ($P < 0.05$) than 'Carolina Cayenne' when plants of both genotypes were inoculated with 6000 and 12000 eggs per plant.

Field expt. 1. 'Carolina Cayenne' was highly resistant in the inoculated field test at Charleston, S.C. For example, roots of 'Carolina Cayenne' exhibited only very slight galling and egg masses were not observed at any inoculum level (Table 3). 'Carolina Cayenne' plants supported essentially no nematode reproduction. Roots of PA-136 and 'Early Calwonder' plants inoculated with 6000 or 12000 eggs per plant were moderately galled (GI = 5.0 to 7.5) and had moderate numbers of egg masses (EMI = 5.0 to 7.5). Numbers of eggs per gram fresh root at harvest were 1.9 to 3.1 times greater ($P < 0.05$) for PA-136 than 'Early Calwonder' at the 6000- and 12000-egg inoculum levels, respectively. Fruit yields were not significantly different at any inoculum level within

Table 2. Comparison of three pepper genotypes differing in resistance to southern root-knot nematode for numbers of *Meloidogyne incognita* eggs and juveniles in soil samples at midseason and harvest, numbers of *M. incognita* eggs extracted from root samples, gall index, egg mass index, and fruit yield, microplot experiment.

Pepper genotype/ inoculum level[z]	No. eggs and juveniles/400 cm^3 soil		Gall index[y]	Egg mass index[x]	No. eggs/g fresh root	Fruit yield (g/plant)
	Midseason	Harvest				
Carolina Cayenne						
0	143 b[w]	110 b	1.0 b	1.0 b	112 c	438 a
6000	2028 b	208 b	1.0 b	1.0 b	191 c	379 ab
12000	110 b	136 b	1.0 b	1.0 b	262 c	413 a
PA-136						
0	1333 b	3681 b	1.0 b	1.0 b	124 c	347 abc
6000	20934 a	46223 a	8.9 a	9.0 a	138291 a	273 c
12000	18640 a	40121a	8.2 a	8.2 a	124702 ab	301 bc
Early Calwonder						
0	205 b	17 b	1.0 b	1.0 b	154 c	617 a
6000	13643 a	43452 a	8.8 a	8.8 a	104416 b	559 a
12000	16514 a	44412 a	8.2 a	8.2 a	111301 b	463 a

[z]Each plant was inoculated with 0, 6000, or 12000 *M. incognita* eggs. The inoculum was applied in split inoculations, one-half at planting and one-half 1 week later.
[y]Gall index: 1 = no galls; 9 = >80% of root system galled.
[x]Egg mass index: 1 = no egg masses; 9 = >80% of root system covered with egg masses.
[w]Means in a column followed by the same letters are not significantly different according to Duncan's multiple range test ($P < 0.05$).
[v]Separate mean comparisons apply to cayenne ('Carolina Cayenne' and PA-136) and bell pepper ('Early Calwonder') fruit yields.

cultivars, and fruit yields of 'Carolina Cayenne' and PA-136 were not significantly different at any inoculum level.

Field expt. ii. Fruit yield of 'Carolina Cayenne' was 339% greater ($P < 0.05$) than fruit yield of the related root-knot susceptible line PA-136. At midseason, soil samples collected from plots where 'Carolina Cayenne' plants were grown had 99.4% fewer ($P < 0.05$) eggs than plots where PA-136 plants were grown. At harvest, soil samples from 'Carolina Cayenne' plots had 97.3% fewer eggs and juveniles than samples from PA-136 plots. 'Carolina Cayenne' roots exhibited only slight galling (GI = 1.4) and very low numbers of egg masses (EMI = 1.4). Roots of PA-136 were severely galled (GI = 9.0) and had extremely large numbers of egg masses (EMI = 8.9).

Discussion

'Carolina Cayenne' exhibited exceptionally high resistance (minimal galling and nematode reproduction and no reduction in yield) in all greenhouse, microplot, and field tests. These results agree with previous reports that galling caused by *M. incognita* and subsequent nematode reproduction are very minimal in 'Carolina Cayenne' (Fery et al., 1986; Zamora et al. 1994). In our experiments, fruit yield of both susceptible checks, 'Early Calwonder' and PA-136, were reduced by *M. incognita*. Our results parallel those from microplot studies in Italy, where fruit weight of the susceptible sweet pepper 'Yolo Wonder' was reduced by *M. incognita* race 1, but fruit size of a resistant breeding line of sweet

Table 3. Comparison of three pepper genotypes differing in resistance to southern root-knot nematode for gall index, egg mass index, numbers of *Meloidogyne incognita* eggs per g fresh root, and fruit yield, field expt. I.

Pepper genotype/ inoculum level[z]	Gall index[y]	Egg mass index[x]	No. eggs/g fresh root	Fruit yield (kg·ha^{-1})
Carolina Cayenne				
0	1.1 c[w]	1.0 c	7 d	19086 a[v]
6000	1.1 c	1.0 c	6 d	17672 a
12000	1.2 c	1.0 c	0 d	16241 a
PA-136				
0	1.0 c	1.0 c	8 d	16159 a
6000	5.9 b	5.1 b	54602 b	16356 a
12000	6.5 a	6.6 a	67403 a	17109 a
Early Calwonder				
0	1.0 c	1.0 c	20 d	5323 b
6000	7.0 ab	7.0 a	28285 c	5993 b
12000	7.4 a	7.4 a	21416 c	5564 b

[z]Each plant was inoculated with 0, 6000, or 12000 *M. incognita* eggs. The inoculum was applied in split inoculations, one-half at planting and one-half 1 week later.
[y]Gall index: 1 = no galls; 9 = >80% of root system galled.
[x]Egg mass index: 1 = no egg masses; 9 = >80% of root system covered with egg masses.
[w]Means in a column followed by the same letter are not significantly different according to Duncan's multiple range test ($P < 0.05$).
[v]Separate mean comparisons apply to cayenne pepper ('Carolina Cayenne' and PA-136) fruit yields and bell pepper ('Early Calwonder') fruit yields.

Table 4. Comparison of two pepper genotypes differing in resistance to southern root-knot nematode for numbers of *Meloidogyne incognita* eggs and juveniles in soil samples, gall index, egg mass index, and fruit yield, field expt. II.

Pepper genotype	No. eggs and juveniles/400 cm^3 soil		Gall index[y]	Egg mass index[x]	Fruit yield (kg·ha^{-1})
	Midseason[z]	Harvest			
Carolina Cayenne	330*	90*	1.4*	1.4*	15899*
PA-136	51963	3322	9.0	8.9	3623

[z]Only eggs extracted at midseason.
[y]Gall index: 1 = no galls; 9 = >80% of root system galled.
[x]Egg mass index: 1 = no egg masses; 9 = >80% of root system covered with egg masses.
*Significant at $P < 0.01$.

pepper was not reduced (Di Vito et al., 1992).

The delayed planting, late inoculation of hardened plants, and subsequent low nematode populations probably contributed to the ability of 'Early Calwonder' and PA-136 plants to sustain their yields in field expt. I. Root galling was much less severe and nematode reproduction was much lower in 'Early Calwonder' and PA-136 plants in field expt. I than in the greenhouse and microplot tests. In field expt. I, roots were galled within the area of inoculation, but feeder roots had grown rapidly enough to escape heavy nematode infection. The reduced length of the host-parasite interaction in field expt. I compared to the microplot experiment is a probable explanation for the very different results between the two tests.

In field expt. I, fruit yields of 'Carolina Cayenne' and PA-136 were very similar when grown in uninoculated methyl bromide-fumigated soils. Thus, yield potential of the susceptible PA-136 and the resistant 'Carolina Cayenne' are comparable. Fruit yields of the uninoculated 'Carolina Cayenne' check plants in field expt. I were similar to the fruit yields of 'Carolina Cayenne' plants of field expt. II that were grown in a field that was heavily infested with *M. incognita*, indicating that 'Carolina Cayenne' fruit yield is not reduced at high populations of root-knot nematode. This is the first report of the high yield potential of 'Carolina Cayenne' when grown in the presence of very high populations of *M. incognita*.

The exceptionally high level of resistance to the southern root-knot nematode expressed in 'Carolina Cayenne' should allow successful production of cayenne peppers in fields that are heavily infested with *M. incognita*. The resistance exhibited by this cultivar is highly effective and inexpensive; it is an environmentally compatible alternative to using methyl bromide or other nematicides to control root-knot nematodes in peppers. Perhaps the greatest contribution of 'Carolina Cayenne' to the pepper industry will be its use as a source of root-knot nematode resistance for developing new bell pepper cultivars. None of the leading bell cultivars currently grown in the United States has adequate resistance to *M. incognita*. Additionally, 'Carolina Cayenne' and pepper cultivars with the 'Carolina Cayenne' resistance factor may be useful as rotation crops in reducing root-knot nematode populations to levels that would allow production of root-knot susceptible vegetable crops.

Literature Cited

Di Vito, M., N. Greco, and A. Carella. 1985. Population densities of *Meloidogyne incognita* and yield of *Capsicum annuum*. J. Nematol. 17:45–49.

Di Vito, M., V. Cianciotta, and G. Zaccheo. 1992. Yield of susceptible and resistant pepper in microplots infested with *Meloidogyne incognita*. Nematropica 22:1–6.

Di Vito, M., F. Saccardo, A. Errico, V. Zema, and G. Zaccheo. 1993a. Genetics of resistance to root-knot nematodes (*Meloidogyne* spp.) in *Capsicum chacoense*, *C. chinense*, and *C. frutescens*. J. Genet. Breed. 47:23–26.

Di Vito, M., F. Saccardo, and G. Zaccheo. 1993b. Response of new lines of pepper to *Meloidogyne incognita, M. javanica, M. arenaria* and *M. hapla*. Afro-Asian J. Nematol. 3:135–138.

Fery, R.L. and P.D. Dukes. 1984. Southern root knot of pepper: Studies on value of resistance. HortScience 19:211. (Abstr.)

Fery, R.L. and P.D. Dukes. 1996. The inheritance of resistance to the southern root-knot nematode in 'Carolina Hot' cayenne pepper. J. Amer. Soc. Hort. Sci. 121:1024–1027.

Fery, R.L., P.D. Dukes, and W.L. Ogle. 1986. 'Carolina Cayenne' pepper. HortScience 21:330.

Hare, W.W. 1957. Inheritance of resistance to root-knot nematodes in pepper. Phytopathology 47:455–459.

Hendy, H., A. Dalmasso, and M.C. Cardin. 1985a. Differences in resistant *Capsicum annuum* attacked by different *Meloidogyne* species. Nematologica 31:72–78.

Hendy, H., E. Pochard, and A. Dalmasso. 1985b. Inheritance of resistance to *Meloidogyne* Chitwood (Tylenchida) in 2 lines of *Capsicum annuum* L.: Study of homozygous progenies obtained by androgenesis. Agronomie 5:93–100.

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

Jenkins, W.R. 1964. A rapid centrifugal-flotation technique for separating nematodes from soil. Plant Dis. Rpt. 48:692.

Lamberti, F. 1979. Economic importance of *Meloidogyne* spp. in subtropical and Mediterranean climates, p. 341–357. In: F. Lamberti and C.E. Taylor (eds.). Root-knot nematodes (*Meloidogyne* species) systematics, biology and control. Academic Press, New York.

Lindsey, D.L. and M.S. Clayshulte. 1982. Influence of initial population densities of *Meloidogyne incognita* on three chile cultivars. J. Nematol. 14:353–358.

Martin, J.A. and J.H. Crawford. 1958. Carolina Hot pepper. South Carolina Agr. Expt. Sta. Circ. 117.

Noe, J.P. 1992. Variability among populations of *Meloidogyne arenaria*. J. of Nematol. 24:404-414.

Sasser, J.N. and D.W. Freckman. 1987. A world perspective on nematology: The role of the society, p. 7-14. In: J.A. Veech and D.W. Dickson (eds.). Vistas on nematology: A commemoration of the twenty-fifth anniversary of the Society of Nematologists. Soc. Nematol., Hyattsville, Md.

Thomas, S.H. and M. Cardenas. 1985. Relationships between preseason numbers of *Meloidogyne incognita* and yield losses in chile pepper cultivars. Phytopathology 75:1304. (Abstr.)

U.S. Department of Agriculture. 1993. Alternatives to methyl bromide: Assessment of research needs and priorities. Proc. USDA workshop on alternatives to methyl bromide. 29 June–1 July 1993, Arlington, Va.

Zamora, E., P.W. Bosland, and S. Thomas. 1994. Carolina Cayenne as a source of resistance to *Meloidogyne incognita* races 1, 2, 3, and 4. HortScience 29:1184-1185.