Tolerance of Carrot to *Meloidogyne hapla*

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ABSTRACT

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Twenty-one cultivars and breeding lines of carrot (*Daucus carota* L.) were assayed for their response to northern root-knot nematode (*Meloidogyne hapla*) under greenhouse conditions. MSU 872 and MSU 5988 were considered tolerant, with three or four galls per root; and MSU 9555, MSU 1394, and Gold Pak 28 were susceptible, with 20–41 galls per root. In muck soil in naturally infested fields, Spartan Classic and MSU 872 were tolerant (averages of 22 and 23% galled roots, respectively), and MSU 1394 and MSU 9555 were susceptible to *M. Hapla* (averages of 45 and 49%, respectively).

The northern root-knot nematode (*Meloidogyne hapla* Chitwood) is a serious pathogen of carrots (*Daucus carota* L.) (2) in Michigan where about 2,700 ha of carrots were harvested in 1979 (1). *M. hapla* and *D. carota* form a complex host-parasite relationship characterized by symptoms including galling, forking, stubbing and fasciculation of the roots, and yield reduction (6,9,10).

Carrot roots attain full length during the first 2–3 wk of growth (9,14) and are most susceptible to *M. hapla* during this period. Obstacles to root elongation such as rocks, nondecomposed organic material, compacted soil and soil insects can also cause taproot malformations (13,14). Pathogens other than *M. hapla* can also cause stubbing, forking, and fasciculation of roots (6). Yield losses and plant mortality due to nematode damage are extensive (6,9). Nematode control by soil fumigation costs approximately \$600–\$1,200/ha on Michigan mucklands.

To study this complex system, conditions must be controlled to eliminate undesirable environmental interactions. This is especially important to carrot breeders selecting for nematode tolerance based on a straight and marketable root shape. The objective of this research was to evaluate carrot breeding lines and cultivars for their response to *M. hapla* under controlled greenhouse conditions.

MATERIALS AND METHODS

Carrot breeding lines and cultivars with various root types (Table 1) were assayed for tolerance to *M. hapla*. The hybrid cultivars and their parents (5) and the standard cultivars have been described (4,12).

Six soil media were evaluated to determine an acceptable medium for nematode infection (Table 2). A steam-sterilized mixture of muck and sand (1:1, v:v) resulted in the induction of the most galls per plant, although this was not significantly different from the sand medium. This medium supplied nutrients to the emerging carrots and could be easily removed from the seedlings with minimal damage to the roots, so that the number of galls could be counted.

Greenhouse evaluation. Nematodes were reared in the greenhouse on tomato (*Lycopersicon esculentum* Mill. 'Rutgers'). The eggs used for inoculum were extracted with a 1.0% NaOCl solution (7), calibrated, refrigerated (5 C) in a water suspension, and used as needed for the experiments.

Based on previous studies (*unpublished*), a concentration of 500 eggs per 100 ml of medium was used as inoculum to produce galls on carrot seedlings. Other screening techniques have involved other inoculum levels (11,15). With 500 eggs per 100 ml of medium, however, the number of galls per plant was such that the carrot roots could be evaluated and classified from susceptible to tolerant to nematode attack.

Three seeds of each breeding line or cultivar were planted into individual 2.5 × 2.5 × 12.5 cm cells of Styrofoam trays (Speedling, Inc., Sun City, FL 33586) and thinned to a single seedling at emergence. Each cell (seed) was inoculated with a suspension of about 370 nematode eggs. The trays were arranged randomly in the greenhouse with periodic overhead misting for 30 sec every 30 min; the soil temperature was 25 ± 2 C.

The life cycle of *M. hapla* is approximately 45 days, but galls can be detected as early as 3 wk after infection (10); therefore, carrot roots were examined for galls 4 wk after inoculation. Each entry was classified for its response

Table 1. Carrot lines and cultivars assayed for their response to *Meloidogyne hapla* in a greenhouse seedling test at 25 C in a sand and muck medium

Entry	Source/lot no.	Root type[a]	Top length (cm)
Cultivar			
Spartan Delux F_1	Crookham	Imperator	>35
Spartan Delite F_1	Crookham	Imperator	20–35
Spartan Fancy F_1	Crookham	Imperator	20–35
Spartan Premium F_1	Crookham	Long Nantes	20–35
Spartan Classic F_1	Crookham	Nantes, Danvers	20–35
Spartan Bonus 80 F_1	Crookham	Danvers	>35
Danvers 126	Northrup King	Danvers	>35
Scarlet Nantes	Northrup King	Nantes	20–35
Gold Pak 28	Ferry Morse	Imperator	20–35
Red Core Chantenay	C6051	Chantenay	>35
Breeding line			
MSU 1394	75W338	Imperator	>35
MSU 5986	71W33	Imperator	20–35
MSU 1302	75W92	Imperator	20–35
MSU 871	C5009	Imperator	<20
MSU 6000	421013	Imperator	<20
MSU 8549	75H2	Imperator, Nantes	<20
MSU 5988	72W161	Long Nantes	20–35
MSU 872	C534	Long Chantenay	20–35
MSU 1475	C5019	Long Chantenay	20–35
MSU 9555	78W190	Chantenay, Danvers	>35
MSU 9541	72W91	Danvers	>35

[a] As described by Babb et al (4).

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to nematode attack by counting the number of galls per plant and arbitrarily dividing them into classes from susceptible to resistant (Table 3).

The experimental design was completely randomized, with 12 replications. Data were subjected to statistical analysis to determine significant differences in nematode response among carrot lines and cultivars.

Field evaluation. The carrot lines and cultivars (Table 1) were also grown and evaluated under field conditions in a Houghton muck soil with a 4-yr history of *M. hapla* infestation. Carrots were seeded on May 10 in single rows 3 m long and 0.5 m apart; approximately 250 seeds were sown per plot, with five replications. After 3 wk the seedlings were thinned to 36 plants/per meter. Standard cultural practices were used for muck-grown carrots (3).

In September, 25 roots were harvested from the center of each plot and examined to determine the percent of galled roots. Nematode infestation was evidenced by the presence of galls on the roots.

The experimental design, a Youden Square (16) with five replications, was chosen to minimize variation in the nematode population throughout the test plot (8). The data were statistically analyzed and the carrot lines and cultivars described by their response to *M. hapla*.

Table 2. Comparison of steam-sterilized media for inducing *Meloidogyne hapla* galls on carrot cultivar Gold Pak 28

Medium	Galls per plant[a]
Sand, muck (1:1, v/v)	19.1 a
Sand	12.6 ab
Muck	10.3 bc
Loam, peat, sand (1:1:1)	5.3 bc
Metro Mix 200[b]	3.0 c
Vermiculite	0.3 c

[a] Means in a column followed by the same letter are not significantly different according to Tukey's HSD test, $P = 0.05$.
[b] Grace Horticultural and Agricultural Products, W. R. Grace and Co., Cambridge, MA 02140.

RESULTS AND DISCUSSION

In the greenhouse studies, the more tolerant breeding lines were MSU 872, MSU 5988, and MSU 1475 (Table 4). The response among breeding lines ranged from 3 to 41 galls per plant. Among cultivars, the number of galls per plant ranged from 6 to 28. Based on number of galls, the tolerant cultivar was Spartan Classic, but differences among most cultivars were not significant. The standard cultivars Gold Pak 28 and Danvers 126, commonly used in carrot production, were generally more susceptible than others.

The breeding lines and cultivars were also tested in fields infested with *M. hapla* (Table 4). The percentage of plants with galled roots varied from 22 to 38% among cultivars and from 23 to 51% among breeding lines. The carrot lines and cultivars were ranked for tolerance to *M. hapla*. There was a significant correlation of field with greenhouse test results among breeding lines ($r = 0.63$, $P = 0.05$). In each test, MSU lines 872, 5988, and 1475 were tolerant to *M. hapla*, and 9555 and 1394 were susceptible. There was no significant correlation between the results of the field and greenhouse tests for the cultivars. This absence of significance might be due to the major change in rank of Spartan Premium and Gold Pak 28.

The root type appeared to be associated with gall formation and *M. hapla* tolerance (Tables 1 and 4). In the field experiment, carrots with Nantes and Long Chantenay root types (Spartan Classic, Spartan Premium, Scarlet Nantes, MSU 8549, MSU 5988, MSU 872, and MSU 1475) exhibited tolerance. These same seven entries, except for Spartan Premium, in greenhouse tests were tolerant to *M. hapla* galling. In both experiments, carrots with Danvers root types, except for Spartan Bonus 80, were susceptible. Spartan Bonus 80 is a three-way hybrid cross of (Long Chantenay × Imperator) × Danvers root types (5). Thus, the Long Chantenay × Imperator maternal parent may exhibit dominance over the susceptible Danvers parental (MSU 9541) root type for *M. hapla* tolerance.

Screening for nematode tolerance in naturally infested fields often leads to the selection of roots that appear to be healthy and tolerant but are actually "escapes" from nematode infestation (8). Our greenhouse seedling test alleviates this possibility and permits rapid controlled screening and evaluation of carrots for root-knot tolerance based on gall formation.

A carrot cultivar with tolerance to *M. hapla* could perhaps be developed based on MSU lines 872, 5988, and 1475. However, carrots must be free of blemishes to be acceptable for fresh-market consumption. Cultivars tolerant or resistant to *M. hapla* must have a resistance mechanism that precludes

Table 3. Tolerance to *Meloidogyne hapla* of carrot lines and cultivars as seedlings in the greenhouse and at maturity in the field

	Greenhouse (no. of galls/root)	Field (% galled roots)
Resistant	0	0–10
Resistant-tolerant		11–20
Tolerant	1–5	21–30
Tolerant-susceptible	6–15	31–40
Susceptible-tolerant	16–25	41–50
Susceptible	>25	>50

Table 4. Tolerance to *M. hapla* of carrot breeding lines and cultivars in the greenhouse and field

	Greenhouse[a]		Field[a]	
Entry	No. of galls/plant	Rank class[b]	% Galled roots	Rank class[b]
Cultivar				
Spartan Classic	6.2 a	1 T-S	21.6 a	1 T
Spartan Delux	6.6 a	2 T-S	28.0 a	5 T
Spartan Bonus 80	7.1 a	3 T-S	24.8 a	3 T
Spartan Delite	7.2 a	4 T-S	28.0 a	5 T
Scarlet Nantes	8.5 a	5 T-S	27.2 a	4 T
Spartan Fancy	8.7 a	6 T-S	24.8 a	3 T
Danvers 126	9.3 a	7 T-S	38.4 a	7 T-S
Red Core Chantenay	13.1 ab	8 T-S	37.6 a	6 T-S
Spartan Premium	20.6 bc	9 S-T	23.2 a	2 T
Gold Pak 28	27.9 c	10 S	28.0 a	5 T
Breeding line				
MSU 872	3.3 a	1 T	23.2 a	1 T
MSU 5988	4.3 a	2 T	28.8 abc	3 T
MSU 1475	5.0 a	3 T	28.8 abc	3 T
MSU 8549	6.2 a	4 T-S	31.2 abcd	4 T-S
MSU 1302	6.6 a	5 T-S	26.4 ab	2 T
MSU 5986	6.7 a	6 T-S	36.0 abcd	5 T-S
MSU 871	7.5 a	7 T-S	51.2 d	10 S
MSU 6000	9.3 a	8 T-S	44.0 abcd	7 S-T
MSU 9541	19.4 a	9 S-T	41.6 abcd	6 S-T
MSU 1394	20.3 a	10 S-T	44.8 bcd	8 S-T
MSU 9555	41.3 b	11 S	48.8 cd	9 S-T

[a] Means in a column followed by the same letter are not significantly different according to Duncan's multiple range test, $P = 0.05$.
[b] T = tolerant and S = susceptible to *M. hapla* attack.

visual damage to the carrot root. Many more lines and cultivars should be screened to identify other sources with tolerance that could be used in carrot breeding programs.

LITERATURE CITED

1. Agriculture Across Michigan. 1979. Michigan vegetable production up 5 percent. Publ. Mich. Agric. Rep. Serv. Vol. 1, No. 24.
2. Anonymous. 1970. Estimated crop losses from plant-parasitic nematodes in the United States. Soc. Nematol. Committee on Crop Losses Special Publ. No. 1, suppl. to J. Nematol. 4 pp.
3. Anonymous. 1978. Vegetable Production Recommendations. Ont. Ministry Agric. Food, Publ. 363. 72 pp.
4. Babb, M. F., Kraus, J. E., and Magruder, R. 1950. Synonomy of orange-fleshed varieties of carrots. U.S. Dep. Agric. Circ. 833. Washington, DC. 100 pp.
5. Baker, L. R. 1978. Spartan hybrid carrot series 1968-1976. Mich. State Univ. Agric. Exp. Stn. Res. Rep. 359. 8 pp.
6. Crete, R. 1977. Diseases of carrots in Canada. Can. Dep. Agric. Publ. 1615. 21 pp.
7. Hussey, R. S., and Barker, K. R. 1973. A comparison of methods of collecting inocula of *Meloidogyne* spp., including a new technique. Plant Dis. Rep. 57:1025-1028.
8. Norton, D. C. 1978. Ecology of Plant-Parasitic Nematodes. John Wiley & Sons, New York. 268 pp.
9. Slinger, L. A., and Bird, G. W. 1978. Ontogeny of *Daucus carota* infected with *Meloidogyne hapla*. J. Nematol. 10:188-194.
10. Taylor, A. L., and Sasser, J. N. 1978. Biology, Identification and Control of Root-knot Nematodes. NC State Univ. Graphics, Raleigh. 111 pp.
11. Vrain, T. C., and Baker, L. R. 1980. Reaction of carrot cultivars to *Meloidogyne hapla*. Can. J. Plant Pathol. 2:163-168.
12. Whitaker, T. W., Sherf, A. F., Lang, W. H., Nicklow, C. W., and Radewald, J. D. 1970. Carrot production in the United States. U.S. Dep. Agric. Handb. 375. Washington, DC. 37 pp.
13. White, J. M. 1978. Soil preparation effects on compaction, carrot yield and root characteristics in organic soil. J. Am. Soc. Hort. Sci. 103:433-435.
14. White, J. M., and Strandberg, J. O. 1978. Early root growth of carrots in organic soil. J. Am. Soc. Hort. Sci. 103:344-347.
15. Wyatt, J. E., and Fassuliotis, G. 1979. Methods for screening snap beans for resistance to root-knot nematodes. HortScience 14:27-28.
16. Youden, W. J. 1940. Experimental designs to increase accuracy of greenhouse studies. Contrib. Boyce Thompson Inst. 11:219-228.