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Responses of Some Common Cruciferae to Root-knot Nematodes[1]

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Abstract: Ten cultivated plants of the family Cruciferae were evaluated for susceptibility to *Meloidogyne arenaria* race 1, *M. incognita* races 1 and 3, and *M. javanica* in a series of four separate greenhouse tests. After 62–64 days, or 1,032–1,072 degree days (10 C base), several of the crops evaluated showed moderate to severe levels of galling (>3.0 on 0–5 scale) and moderate numbers of egg masses (>2.0 on 0–5 scale) in response to each of the nematode species and races. Among the plants tested, collard (*Brassica oleracea* var. *acephala*) cv. Georgia Southern was the least susceptible (fewest galls and egg masses) to each of the four nematode isolates. Similar low levels of infection were obtained with broccoli (*B. oleracea* var. *botrytis*) cv. De Cicco in response to *M. incognita* race 1 and *M. arenaria*. Numbers of second-stage juveniles hatched from eggs per root system were variable in the test with *M. arenaria*, but lowest on collard for each of the other nematodes. Some commonly grown crucifers are hosts to several different species and races of *Meloidogyne*, which should be considered if these crops are included in cropping systems.

Key words: *Brassica chinensis, Brassica napus, Brassica oleracea, Brassica rapa*, broccoli, cabbage, canola, cauliflower, chinese cabbage, collard, host-plant resistance, *Meloidogyne arenaria, Meloidogyne incognita, Meloidogyne javanica*, mustard, nematode, radish, *Raphanus sativus, Sinapis alba*, turnip.

Plants of the family Cruciferae are receiving increased attention as novel tools for the management of plant-parasitic nematodes. Decomposition products from crucifers can be suppressive to plant pathogens (8), and recent studies (6,12,13) have examined the potential for nematode suppression by canola or rapeseed (*Brassica napus*) used as a green manure. Other cruciferous crops are being investigated as potential trap crops for *Heterodera schachtii* (2); however, cruciferous trap crops may be hosts for nontarget nematode pests, such as *Meloidogyne* spp. (3). If rapeseed for green manure is grown *in situ*, then reproduction of *Meloidogyne* spp. may be a concern. Although reproduction of *Meloidogyne* spp. on rapeseed or canola was low in the field during the winter months (6), several *Meloidogyne* spp. reproduced well on this host in the greenhouse at temperatures >22 C (1,13; R. A. Kinloch, pers. comm.).

Several of the commonly cultivated Cruciferae are hosts to one or more species of *Meloidogyne* (4,14). As emphasis on cultural practices for management of plant-parasitic nematodes increases, the numbers and diversity of potential crops to include in rotations or cropping systems should be increased (9,11). If cruciferous crops are to be included in cropping systems in the southeastern United States, their host status to the major nematode pests of the region must be determined. The objective of our study was to determine the relative host suitability of some commonly cultivated Cruciferae to several common root-knot nematodes in Florida: *M. arenaria* race 1, *M. incognita* races 1 and 3, and *M. javanica*.

Materials and Methods

Four separate greenhouse experiments were conducted, each with a different *Meloidogyne* isolate. The Cruciferae included in the tests were canola cv. A112; broccoli (*B. oleracea* var. *botrytis*) cv. De Cicco; collard (*B. oleracea* var. *acephala*) cv. Georgia Southern; cauliflower (*B. oleracea* var. *botrytis*) cv. Early Snowball A; radish (*Raphanus sativus*) cv. Cherry Belle; turnip (*B. rapa*) cvs. Purple Top White Globe Nabo and Nabo Seven Top; cabbage (*B. oleracea* var. *capitata*) cv. Copenhagen Early Market; mustard (*Sinapis alba*) cv. Florida

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Broad Leaf; and chinese cabbage (*B. chinensis* var. *pekinensis*) cv. Orient Express. Individual seeds of these plants were planted in 5-cm × 5-cm plastic trays in steam-sterilized soil (92% sand, 3% silt, 5% clay; pH 6.0; 1.3% organic matter). Three weeks after planting, seedlings were transplanted (1/pot) into the same soil mix in 12.5-cm-d plastic pots with a capacity of approximately 825 cm^3 soil.

One day after transplanting, the soil in each pot was infested with 1,000 second-stage juveniles (J2) of the appropriate *Meloidogyne* isolate. Inocula were prepared from isolates of *M. arenaria* race 1, *M. incognita* races 1 and 3, and *M. javanica* maintained in a greenhouse on tomato (*Lycopersicon esculentum* cv. Rutgers) (10) and verified by differential host tests (17). Four days before soil infestation, eggs of a given nematode isolate were extracted from tomato roots in 0.525% NaOCl (5). Extracted eggs were incubated at 22 C on modified Baermann trays (15) for collection of J2, which were delivered into two holes (2 cm deep; 500 J2/hole) in the soil at the base of the seeding.

Treatments for each test consisted of the 10 cruciferous cultivars listed above, except for the test with *M. arenaria,* from which radish was omitted. Two Rutgers tomato plants were included with each experiment to confirm viability of inoculum. Each experiment was arranged on raised benches in randomized complete blocks with six replications and maintained in a greenhouse with daily mean temperatures of 21–29 C. Plants were watered as needed and fertilized every 2 weeks with 3.8 g/liter of a 20:20:20 (total $N:P_2O_5:K_2O$) soluble fertilizer. Whiteflies were managed as needed with sprayed applications of 18.5 ml/liter of a 49% (w:w) concentrate of potassium salts of fatty acids (Safer Insecticide Concentrate, Newton, MA).

The experiments with the different *Meloidogyne* spp. differed in their starting (infestation) dates, duration in days, and total degree days (10 C base) accumulated (DD_{10}), as follows: *M. javanica,* 6 January 1994, 64 days (1,052 DD_{10}); *M. incognita* race 1, 13 January, 63 days (1,032 DD_{10}); *M. incognita* race 3, 28 January, 62 days (1,053 DD_{10}); *M. arenaria,* 11 February 1994, 62 days (1,072 DD_{10}). At the termination of each experiment, root systems were washed free of soil, and galls and egg masses were rated on a 0–5 scale, as follows: 0 = 0 galls; 1 = 1–2; 2 = 3–10; 3 = 11–30; 4 = 31–100; and 5 = >100 galls or egg masses per root system (17). Eggs were extracted in 0.525% NaOCl (5) and incubated on Baermann trays as described for inoculum preparation to obtain hatched J2, which were counted and reported as number of J2 per root system. This method confirms viability of extracted eggs and avoids confusion between eggs of *Meloidogyne* spp. and eggs of Rhabditidae, which occasionally colonize soil and plant root surfaces even under greenhouse conditions.

All data were subjected to analysis of variance followed by mean separation ($P < 0.05$) with the Student-Newman-Keuls test (16). Gall and egg mass ratings were not transformed, but nematode count data were transformed by $\log_{10}(x + 1)$ values before analysis, although untransformed arithmetic means are presented in the tables.

Results

Results of the four experiments were similar. In all experiments, every tomato plant was heavily galled and had numerous egg masses (ratings = 4 or 5), confirming the viability of the inoculum (data not included in analyses). Many of the crucifers had gall ratings of ≥3.0 in response to each root-knot nematode isolate (Table 1). Galls were small and usually outnumbered egg masses on these hosts; however, gall and egg mass ratings were similar on most plants in the test with *M. arenaria.* Regardless of nematode species, the lowest gall and egg mass ratings were always found on collard. Gall and egg mass levels on broccoli did not differ from those on collard in response to *M. incognita* race 1 or *M. arenaria* ($P > 0.05$). Occasionally, responses of

TABLE 1. Root-gall indices, egg-mass ratings, and numbers of juveniles hatched from eggs extracted per root system on Cruciferae grown in soil infested with *Meloidogyne javanica* (Mj), *M. incognita* race 1 (Mi1), *M. incognita* race 3 (Mi3), or *M. arenaria* race 1 (Ma).

Plant	Cultivar	Root-gall rating[a]				Egg-mass rating				Juveniles per root system			
		Mj	Mil	Mi3	Ma	Mj	Mil	Mi3	Ma	Mj	Mil	Mi3	Ma
Canola	A112	3.00 a	2.75 a	3.75 ab	3.70 ab	1.17 b	0.50 c	2.25 d	3.60 a	228 ab	619 a	2,476 a	806 a
Broccoli	De Cicco	3.67 a	1.42 d	3.17 b	2.90 bc	1.50 ab	0.50 c	2.08 d	2.00 b	94 ab	42 b	929 ab	256 a
Collard	Georgia Southern	1.44 b	1.08 d	2.33 c	2.70 c	0 c	0.42 c	0.83 e	1.80 b	14 b	2 c	425 b	268 a
Cauliflower	Early Snowball A	2.94 a	3.83 ab	4.17 ab	4.25 a	2.17 ab	2.33 b	3.67 abc	4.12 a	118 ab	80 b	1,691 ab	185 a
Radish	Cherry Belle	3.06 a	3.67 ab	3.75 ab	—	1.39 ab	1.75 b	2.50 d	—	12 b	440 a	1,960 ab	—
Turnip	Purple Top White Globe Nabo	3.58 a	4.25 ab	41.7 ab	4.40 a	2.33 a	2.58 ab	3.83 ab	4.50 a	420 ab	1,191 a	2,897 a	1,676 a
Cabbage	Copenhagen Early Market	3.33 a	3.50 bc	3.75 ab	3.70 ab	2.50 a	2.08 b	2.58 cd	3.60 a	200 ab	233 ab	2,702 a	389 a
Mustard	Florida Broad Leaf	3.39 a	4.42 ab	4.08 ab	4.40 a	1.89 ab	2.83 ab	3.25 bcd	4.00 a	2,214 a	526 a	3,405 a	1,065 a
Chinese cabbage	Orient Express	3.78 a	4.33 ab	4.58 a	4.40 a	2.39 a	3.67 a	4.42 a	4.40 a	163 ab	666 a	1,879 ab	866 a
Turnip	Nabo Seven Top	3.50 a	4.67 a	4.08 ab	3.80 ab	1.89 ab	3.58 a	3.08 bcd	3.60 a	313 ab	1,043 a	1,545 ab	916 a

Means in columns followed by the same letter do not differ ($P \leq 0.05$) by the Student-Newman-Keuls test.

[a] Root galling and egg masses rated on a 0–5 scale as follows: 0 = 0 galls; 1 = 1–2; 2 = 3–10; 3 = 11–30; 4 = 31–100; 5 = >100 galls or egg masses per root system (17).

canola (egg masses of *M. javanica* or *M. incognita* race 3 and galling by *M. incognita* race 1) were intermediate between those of collard and the more heavily infected plants.

Numbers of J2 hatched per root system were highly variable in the test with *M. arenaria,* and no differences were observed among the plants tested ($P \leq 0.05$) (Table 1). With the other three nematodes, the lowest or equivalent-to-lowest numbers of J2 were obtained from collard. Numbers of J2 recovered per root system were greatest in the test with *M. incognita* race 3, although nematode isolates were not compared statistically. Numbers of J2 recovered extremely low for *M. javanica* and *M. incognita* race 1 on collard.

Discussion

Although all experiments were conducted under similar conditions, because they were conducted at different times it is not possible to compare host suitabilities among *Meloidogyne* isolates. The number of eggs produced per egg mass may be higher for *M. incognita* race 3 than for *M. arenaria,* but further research is required to confirm this observation.

The results indicate that several commonly grown crucifers are hosts of all four *Meloidogyne* species and races tested and that several of these will support moderate (rating >3.0) or relatively high (rating >4.0) levels of galling and egg masses. These results were obtained in the greenhouse at relatively warm temperatures (1,050 DD_{10} in 62 days corresponds to a mean temperature of 27 C). Other tests conducted recently confirm the susceptibility of other crucifers to *M. incognita* and *M. javanica* under greenhouse conditions (1,3). Relatively little nematode reproduction was observed on canola grown in the field in Georgia (6) and Florida (R. A. Kinloch, *pers. comm.*), but these plants were grown during the winter months when low temperatures may have reduced nematode activity (1,6; R. A. Kinloch, *pers. comm.*). Additional work is needed to determine reproduction of *Meloidogyne* spp. on different crucifers at the lower soil temperatures typical of the Southeast during the winter.

Based on our results, the collard cv. Georgia Southern and in some instances the broccoli cv. De Cicco were the most effective in maintaining low number of *Meloidogyne* spp. Therefore, these cultivars may be useful in cropping systems to reduce population densities of *Meloidogyne* spp. Of course, results may vary widely with cultivar. For example, the cauliflower cv. Early Snowball A was susceptible to all root-knot nematode isolates we tested, and many other cauliflower cultivars are susceptible to *M. javanica* and to all races of *M. incognita* (7). In contrast, some cauliflower cultivars had varying degrees of resistance to *M. javanica* and one or more races of *M. incognita,* and one cultivar was not a host to any of the nematodes tested (7). As more information becomes available on the responses of the many cultivars of other Cruciferae to *Meloidogyne* spp., the opportunities to include crucifers in cropping systems for nematode management will increase.

Literature Cited

1. Bernard, E. C., and M. E. Montgomery-Dee. 1993. Reproduction of plant-parasitic nematodes on winter rapeseed (*Brassica napus* ssp. *oleifera*). Supplement to the Journal of Nematology 25:863–868.

2. Gardner, J., and E. P. Caswell-Chen. 1993. Penetration, development, and reproduction of *Heterodera schachtii* on *Fagopyrum esculentum, Phacelia tanacetifolia, Raphanus sativa, Sinapis alba,* and *Brassica oleracea.* Journal of Nematology 25:695–702.

3. Gardner, J., and E. P. Caswell-Chen. 1994. *Raphanus sativus, Sinapis alba,* and *Fagopyrum esculentum* as hosts to *Meloidogyne incognita, Meloidogyne javanica,* and *Plasmodiophora brassicae.* Supplement to the Journal of Nematology 26:756–760.

4. Goodey, J. B., M. T. Franklin, and D. J. Hooper. 1965. T. Goodey's the nematode parasites of plants catalogued under their hosts. Farnham Royal, UK: Commonwealth Agricultural Bureaux.

5. 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.

6. Johnson, A. W., A. M. Golden, D. L. Auld, and D. R. Sumner. 1992. Effects of rapeseed and vetch as green manure crops and fallow on nematodes and soil-borne pathogens. Journal of Nematology 24: 117–126.

7. Khan, A. A., and M. W. Khan. 1991. Reaction of cauliflower cultivars to *Meloidogyne javanica* and races of *Meloidogyne incognita.* Nematropica 21:161–166.

8. Lewis, J. A., and G. C. Papavizas. 1971. Effect of sulfur-containing volatile compounds and vapors from cabbage decomposition on *Aphanomyces euteiches.* Phytopathology 61:208–214.

9. McSorley, R. 1994. Nematode management in sustainable agriculture. Pp. 517–522 *in* K. L. Campbell, W. D. Graham, and A. B. Bottcher, eds. Environmentally sound agriculture. Proceedings of the second conference. St. Joseph, MI: American Society of Agricultural Engineers.

10. McSorley, R., and J. J. Frederick. 1994. Response of some common annual bedding plants to three species of *Meloidogyne.* Supplement to the Journal of Nematology 26:773–777.

11. McSorley, R., and R. N. Gallaher. 1991. Managing plant-parasitic nematodes in crop sequences. Soil and Crop Science Society of Florida Proceedings 51:42–45.

12. Mojtahedi, H., G. S. Santo, A. N. Hang, and J. H. Wilson. 1991. Suppression of root-knot nematode populations with selected rapeseed cultivars as green manure. Journal of Nematology 23:170–174.

13. Mojtahedi, H., G. S. Santo, J. H. Wilson, and A. N. Hang. 1993. Managing *Meloidogyne chitwoodi* on potato with rapeseed as green manure. Plant Disease 77:42–46.

14. Potter, J. W., and T. H. A. Olthof. 1993. Nematode pests of vegetable crops. Pp. 171–207 *in* K. Evans, D. L. Trudgill, and J. M. Webster, eds. Plant-parasitic nematodes in temperate agriculture. Wallingford, UK: CAB International.

15. Rodriguez-Kabana, R., and M. H. Pope. 1981. A simple incubation method for the extraction of nematodes from soil. Nematropica 11:175–186.

16. Sokal, R. R., and F. J. Rohlf. 1969. Biometry. San Francisco, CA: W. H. Freeman.

17. Taylor, A. L., and J. N. Sasser. 1978. Biology, identification, and control of root-knot nematodes (*Meloidogyne* species). Raleigh, NC: North Carolina State University Graphics.