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# *Raphanus sativus*, *Sinapis alba*, and *Fagopyrum esculentum* as Hosts to *Meloidogyne incognita*, *Meloidogyne javanica*, and *Plasmodiophora brassicae*[1]

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*Abstract:* Cultivars of oilseed radish (*Raphanus sativus* var. *oleifera* cv. Adagio, Nemex, Pegletta, Renova, Siletina, Siletta Nova, and Ultimo), white mustard (*Sinapis alba* cv. Albatross, Emergo, Maxi, Martigena, Metex, and Serval), buckwheat (*Fagopyrum esculentum* cv. Prego, Tardo), and phacelia (*Phacelia tanacetifolia* cv. Angelia) were tested for susceptibility to *Meloidogyne incognita* race 3 and *Meloidogyne javanica*. Experiments were conducted in growth chambers at 25 C and 16 hours light for 42 days after inoculation with second-stage juveniles (J2). All cultivars were susceptible to *M. incognita* and *M. javanica*. The oilseed radish (cv. Nemex, Pegletta, and Renova) and white mustard (cv. Emergo) were also examined to determine the influence of *Heterodera schachtii* on susceptibility to *Plasmodiophora brassicae* as measured by incidence and severity of root galling. All cultivars were susceptible, and neither the severity nor incidence of clubroot galling was affected by *H. schachtii*.

*Key words:* buckwheat, clubroot of crucifers, *Fagopyrum esculentum*, *Meloidogyne incognita*, *Meloidogyne javanica*, nematode, oilseed radish, *Phacelia tanacetifolia*, *Plasmodiophora brassicae*, *Raphanus sativus*, root-knot nematode, *Sinapis alba*, trap crop, white mustard.

Effective trap crops for plant-parasitic nematodes are plants that allow nematode penetration but support little or no reproduction. This ensures minimization of nematode reproduction without the necessity of monitoring nematode development on the trap crop. For example, cultivars of oilseed radish (*Raphanus sativus* var. oliefera), white mustard (*Sinapis alba*), and buckwheat (*Fagopyrum esculentum*) have been developed as trap crops for *Heterodera schachtii* in Europe (1).

Trap crops should suppress the primary target organism but not aggravate other pest problems. Root-knot nematodes, *Meloidogyne incognita* and *M. javanica*, parasitize sugarbeet and cole crops (8) and have been found in many production fields in California's Central Valley and coastal counties (16) where sugarbeet and cole crops are rotated with other susceptible crops. *Plasmodiophora brassicae*, the clubfoot fungus, is widespread in California (12,17). Thus, root-knot nematodes and the clubroot fungus are often present in California cole and sugarbeet growing areas where trap crops might be used to manage *H. schachtii*. The value of oilseed radish, white mustard, or buckwheat for management of *H. schachtii* in sugarbeet growing areas is uncertain, because it is not known whether their use will exacerbate diseases caused by *Meloidogyne* spp. or *P. brassicae*. This research was conducted to assess whether certain cultivars of oilseed radish, white mustard, or buckwheat were hosts for *M. incognita*, *M. javanica* or *P. brassicae*.

## MATERIALS AND METHODS

*Meloidogyne incognita experiment:* Treatments consisted of the following plants: oilseed radish cultivars Adagio, Nemex, Pegletta, Renova, Siletina, Siletta Nova, and Ultimo; white mustard cultivars Albatross, Emergo, Maxi, Martigena, Metex, and Serval; buckwheat cultivars Prego and Tardo; and phacelia cv. Angelia. The susceptible control was tomato, *Lycopersicon esculentum* cv. UC82. All seeds were from P. H. Petersen Saatzucht, Lundsgaard, Germany, except for Martigena and Renova (from KWS Kleinwanzlebener Saatzucht AG, Einbeck, Germany), and UC82 tomato (from Sunseeds Genetics, Hollister,

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CA). The bottoms of 73-ml snap-cap vials (Baxter Diagnostics, Inc. Hayward, CA) were perforated once with a 3.0-mm hole, and a 2.5-cm-d circular nylon mesh was placed in the bottom of each vial to prevent sand loss. Vials were filled with 60 $cm^3$ dry silica sand (No. 60 silica sand, Corona Industrial Sand, Corona, CA) for a final weight of approximately 83.5 g sand per vial.

Seeds were germinated at 25 C on moist filter paper in Petri dishes. A single seedling was transplanted into each vial, to which was added 3.0 ml of an aqueous suspension containing 573 *M. incognita* second-stage juveniles (J2)/ml, for a final concentration of approximately 29 J2/$cm^3$ sand. The *M. incognita* (race 3) originated from cotton in Tulare County, California, and was maintained in greenhouse culture on UC82. Following inoculation, vials were irrigated until the entire sand column was wetted. All vials were arranged in a completely randomized design in a growth chamber at 25 C and 24 hours light. Vials were watered daily and received half-strength Hoagland's solution every fifth day (11). Forty-two days after inoculation, roots were gently rinsed free of sand, and entire root systems were stained with acid-fuchsin (3). Stained root systems were pressed between glass plates (7.5 × 5.0 $cm^2$), and the number of adult females was determined at ×40 magnification. The experiment was repeated. In the second trial, seedlings grew for 10 days before inoculation, and the inoculum level was reduced to approximately 10 J2/$cm^3$ sand.

The mean numbers of adult nematodes per cultivar were assigned Wilcoxon ranked sum scores that were subjected to a chi-square approximation of the Kruskal-Wallis test (9). Treatment rank scores were compared using Dunn's method for significant differences ($P \leq 0.05$) between treatments (6).

*Meloidogyne javanica experiment:* The experiment was conducted twice as described for *M. incognita,* except that plants grew for 5 days (trial 1) and 8 days (trial 2) before inoculation with J2. In both trials vials were infested with approximately 13 J2/$cm^3$ sand of *M. javanica* from hydroponic cultures (11). The *M. javanica* was obtained from longstanding U. C. Davis greenhouse cultures (currently designated strain VW4) maintained on tomato (UC82). Statistical analyses were the same as for Experiment 1.

*Plasmodiophora brassicae experiment:* One cultivar of cabbage, one cultivar of white mustard, and three cultivars of oilseed radish were inoculated with clubfoot fungus *(P. brassicae),* either alone or with sugarbeet-cyst nematode (*H. schachtii*). Oilseed radish cultivars Nemex, Pegletta, and Renova were chosen because they showed resistance to *P. brassicae* in preliminary experiments (data not included). Also in those experiments, white mustard, cv. Emergo, and cabbage (*Brassica oleracea* var *capitata* L.) cv. Copenhagen Market, showed susceptibility. *Plasmodiophora brassicae* resting spores were obtained from macerated roots of infected Brussels sprouts (*Brassica oleracea* var. *gemmifera*) poured through cheesecloth and strained through a 20-μm-pore sieve to remove debris. The *P. brassicae* race was not determined, but was probably race 7 (4). *Heterodera schachtii* inoculum was cultured on Copenhagen Market cabbage in greenhouses, and J2 were collected from cysts placed on Baermann funnels (2). The isolates of *P. brassicae* and *H. schachtii* originated in Half Moon Bay, California. Vials were filled as described for the *Meloidogyne* trials. Fourteen days after transplanting, 10 replicates of each treatment were inoculated with approximately 8.3 J2/$cm^3$ of *H. schachtii.* Three days later (17 days after transplanting), plants in all vials (20 vials/cultivar) were inoculated with approximately $3.0 \times 10^6$ *P. brassicae* resting spores/$cm^3$ sand and were arranged in a completely randomized design in a growth chamber and held at 25 C and 16 hours light. All vials were watered daily but received half-strength Hoagland's solution every fourth day. Forty-six days after inoculation with *P. brassicae,* roots were rinsed and rated for clubroot galling with an in-

teger scale as follows: 0 (no galling), 1 (1–20% galling), 2 (21–40% galling), 3 (41–60% galling), 4 (61–80% galling), or 5 (80–100% galling). Treatment means were calculated from the average gall rating per vial. Data were analyzed for interaction of *H. schachtii* and *P. brassicae* by Fisher's Exact Test (15,18). Data from all 20 replicates/cultivar were pooled and gall ratings were analyzed by one-way analysis of variance (18) for significant ($P \leq 0.05$) differences among cultivars with SAS programs (15).

## Results

*Meloidogyne incognita experiment:* The mean number of adult females per plant in trial 1 ranged from 9 for oilseed radish cv. Siletina to 140 for oilseed radish cv. Adagio (Table 1). Siletina had fewer ($P \leq 0.05$) female nematodes than did Adagio or white mustard cv. Metex. Plant mortality in the tomato control treatment did not allow comparison of other treatments to a known susceptible control in the first replicate of this experiment. In trial 2, the mean number of adult females/plant ranged from 4 for oilseed radish cv. Siletta Nova to 177 for white mustard cv. Metex. Siletta Nova had fewer nematodes than did tomato or white mustard cv. Martigena and Metex (Table 1). Tomato had more adult females than did oilseed radish cv. Siletta Nova. Although egg production was not quantified, eggs were present in all samples.

*Meloidogyne javanica experiment:* The mean number of adult females per plant in trial 1 ranged from 13 for phacelia cv. Angelia to 321 for oilseed radish cv. Ultimo (Table 1). In trial 2, the mean number of adult females per plant ranged from 141 to phacelia to 357 for oilseed radish cv. Adagio. In both trials, the mean number of adult females per plant in tomato was no different ($P \leq 0.05$) from that in other cul-

Table 1. Numbers of adult females of *Meloidogyne incognita* race 3, *M. javanica*, and root galls caused by *Plasmodiophora brassicae* on roots of crops.

| | | *M. incognita* females‡ Trial† | | *M. javanica* females§ Trial | | Root-gall index‖ Trial | |
|---|---|---|---|---|---|---|---|
| Genus | Cultivar | 1 | 2 | 1 | 2 | 1 | 2 |
| *Brassica* | Copenhagen Market | — | — | — | — | 3.2 a | 1.6 a |
| *Lycopersicon* | UC82 | — | 155 b | 147 ab | 217 ab | — | — |
| *Phacelia* | Angelia | — | 10 ab | 13 a | 141 a | — | — |
| *Fagopyrum* | Tardo | 42 ab | — | 47 ab | 162 a | — | — |
| | Prego | 70 ab | 23 ab | 110 ab | 172 ab | — | — |
| *Sinapis* | Albatross | 60 ab | — | 210 ab | 213 ab | — | — |
| | Emergo | 70 ab | 68 ab | 316 ab | 205 ab | 1.9 b | 0.9 b |
| | Martigena | 61 ab | 149 b | 221 ab | 242 ab | — | — |
| | Maxi | 56 ab | 117 ab | 161 ab | 260 ab | — | — |
| | Metex | 125 b | 177 b | — | 231 ab | — | — |
| | Serval | 64 ab | 79 ab | 306 ab | 265 ab | — | — |
| *Raphanus* | Adagio | 140 b | 80 ab | 297 ab | 357 b | — | — |
| | Nemex | 77 ab | 49 ab | 171 ab | 294 ab | 0.1 d | 0.1 c |
| | Pegletta | 53 ab | 53 ab | — | 179 ab | 0.2 c | 0.1 c |
| | Renova | 68 ab | 102 ab | 137 ab | 290 ab | 0.9 c | 0.2 c |
| | Siletina | 9 a | 84 ab | 207 ab | 244 ab | — | — |
| | Siletta Nova | 30 ab | 4 a | 192 ab | 320 ab | — | — |
| | Ultimo | — | 45 ab | 321 b | 316 ab | — | — |

† Data are means of five replicates for *M. incognita* and *M. javanica* and 20 replicates for *P. brassicae*. Significance was determined by Dunn's (6) method for multiple comparisons of Wilcoxon's rank sums. Numbers followed by the same letters in a column are not significantly different ($P \leq 0.05$).

‡ *Meloidogyne incognita* was inoculated at 29 J2/cm$^3$ sand (trial 1) and 10 J2/cm$^3$ sand (trial 2) and held in a growth chamber for 42 days at 25 C.

§ *Meloidogyne javanica* was inoculated at 13.5 J2/cm$^3$ sand and held in a growth chamber for 42 days at 25 C.

‖ *Plasmodiophora brassicae* was inoculated at $3.0 \times 10^6$ resting spores/cm$^3$ sand and held for 46 days at 25 C. Gall scale used was 0 (no galling), 1 (1–20% galling), 2 (21–40% galling), 3 (41–60% galling), 4 (61–80% galling) or 5 (80–100% galling).

tivars (Table 1). As in Experiment 1, eggs were always present with adult females but were not counted.

*Plasmodiophora brassicae experiment:* All cultivars showed some susceptibility to *P. brassicae* (Table 1), but the presence of *H. schachtii* did not influence the severity or incidence of clubroot galling on any of the cultivars tested (data not presented). In both trials, the oilseed radish cv. Nemex had the lowest mean gall rating and cabbage had the highest mean gall rating (Table 1).

## Discussion

Our data lead us to suggest that control of sugarbeet-cyst nematode using the plant cultivars examined here is not recommended if *M. incognita* or *M. javanica* is present. All of the cultivars tested were susceptible, and *M. incognita* and *M. javanica* populations will increase on these crops if they are grown when soil temperatures are high enough for penetration and reproduction. However, planting these cultivars as trap crops when soil temperatures are low may provide *H. schachtii* control without allowing root-knot nematode penetration. Microplot studies in Davis, California (7), indicate that cool season plantings of white mustard cv. Martigena or oilseed radish cultivars Nemex, Pegletta, or Renova may be effective for reducing *H. schachtii* populations. Development and reproduction of *H. schachtii* will occur at temperatures as low as 8 C (5). Optimal developmental temperatures for *M. incognita* and *M. javanica* are 25–30 C (19); however, Roberts et al. (14) observed that *M. incognita* was incapable of penetration, and hence subsequent development, on winter wheat sown when soil temperatures were below 16 C. *Meloidogyne javanica* is reported as more susceptible to cool temperatures than *M. incognita* (19), so growing the trap crops when temperatures are low might allow management of *H. schachtii* without *M. incognita* or *M. javanica* numbers increasing.

Clubroot galling was lower on oilseed radishes than on cabbage or white mustard, although all cultivars were galled to some extent. This agrees with Ohlsson's (13) general conclusion that oilseed radish was more resistant to *P. brassicae* than was white mustard. Although oilseed radish and white mustard are equally colonized by clubroot primary plasmodia, it is reported that gall-forming secondary plasmodia do not develop in the root cortex of oilseed radish (10). Because the data from previous experiments (7) indicate that the oilseed radish cultivars Nemex and Pegletta suppressed *H. schachtii,* these cultivars may be the best choice where *H. schachtii* and *P. brassicae* are both problems associated with cole crop production.

Based on this and previous research (7), management of sugarbeet cyst nematode may be possible using selected cultivars of oilseed radish, white mustard, or buckwheat as trap crops. Cultivar selection, proper time of planting, and removal of the trap crop prior to nematode reproduction will be necessary. Additional research is in progress to optimize the performance of tested cultivars and to further assess the potential for adoption by California growers for *H. schachtii* management.

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