Phytopathol. Mediterr. (2004) 43, 360–368

Effect of *Meloidogyne javanica* and *M. incognita* on resistance of muskmelon cultivars to Fusarium wilt

Ihssan Naji[1] and Walid Abu-Gharbieh[2]

[1] University of Jordan, P.O.Box. 212549, 11121, Amman, Jordan
[2] Plant Protection Department, Faculty of Agriculture, University of Jordan, P.O. Box 13287, 11942 Amman, Jordan

Summary. A growth chamber experiment was conducted to study the interaction between *Meloidogyne javanica* and/or *M. incognita* and the Fusarium wilt fungus *Fusarium oxysporum* f. sp. *melonis*, using three muskmelon cultivars differing in their resistance to the fungus. Inoculations were carried out l. with the wilt fungus alone, 14 and 28 days after transplanting; and 2. with the wilt fungus plus one or both root-knot nematodes, either directly upon transplanting, or 14 or 28 days after transplanting. In the course of the test all muskmelon cultivars, irrespective of their initial resistance to the wilt, almost completely lost their resistance when infected with *M. javanica*; resistance was also impaired but to a lesser extent with *M. incognita*. Wilting of 100% in the resistant and moderately resistant muskmelon cultivars inoculated with *M. javanica* + *F. oxysporum* f. sp *melonis* occurred 14 days earlier than in muskmelon inoculated with the fungus alone. Also, *M. javanica* was more severe on the plants than *M. incognita*. In all three cultivars, both root-knot nematode species hastened expression of plant wilting, which took 12.1 days with *M. javanica*, 14.8 days with *M. incognita,* and 12.3 days with both species combined, compared with 22.7 days for plants inoculated with *Fusarium oxysporum* f. sp. *melonis* alone. Moreover, the onset of wilting required 9–13.3 days when the nematode infection preceded *F. oxysporum* f. sp. *melonis* inoculation by two weeks, compared with 16.7–19.7 days when the nematode and fungus were inoculated simultaneously 14 days after transplanting, indicating plant preconditioning by the nematode.

Key words: breakdown of resistance, *Cucumis melo,* fusarium wilt complex, root-knot nematodes.

Introduction

Muskmelon (*Cucumis melo* L.), is one of the most important summer crops in the world (Yamaguchi, 1983). Muskmelons suffer from many diseases that limit their yield. *Fusarium oxysporum* Schlechtend f. sp. *melonis* (Leach & Currence) Snyder and Hans (*Fom*) is one of the most serious pathogens of muskmelon, causing mortality of 90% and more (Sohi and Shrama, 1998). Root-knot nematodes are also one of the most important causes of plant diseases in the world (Sasser, 1980). The conditions required for muskmelon production are very similar to those that also favour both Fusarium wilt development (Armstrong and Armstrong, 1978; Punja *et al.*, 2001) and nematode activity (Freckman and Caswell, 1985). In the soil many pathogens occur together and some establish associations, interactions or complexes. *Meloidogyne* spp. and *Fusarium oxysporum* are a good example of such an association (Sikora and Carter, 1987). But although muskmelons suffer greatly from Fusarium wilt in many parts of the world, and are

Corresponding author: W. Abu-Gharbieh
Fax: +962 6 5355577
E-mail: abugharb@ju.edu.jo

also affected by root-knot nematodes, they are rarely used as a test crop to study the Fusarium - root-knot nematode complex.

This investigation was designed to study the effect of *Meloidogyne javanica* (Treub) Chitwood and *M. incognita* (Kofoid and White) Chitwood, separately and together, on muskmelon wilt caused by *Fom,* to evaluate how muskmelon cultivars are preconditioned by the time of nematode inoculation, and how nematodes lower or remove muskmelon resistance to *Fom* in three cultivars classed as resistant, moderately resistant, and moderately susceptible to Fusarium wilt.

Materials and methods

Plant material

Three muskmelon cultivars differing in their resistance to *Fom* were tested. For cultivar selection, the seeds of twelve muskmelon cultivars were obtained from the National Center for Agricultural Research and Technology Transfer (NCARTT) in Baqa'a, Jordan. Seeds were grown in sterilized trays containing sterilized peat moss. Seedlings (one plant per pot) were inoculated with *Fom* at the first true-leaf stage. One ml of inoculum suspension (10^6 conidia ml^{-1}) was applied to each seedling using a pipette (Latin and Snell, 1986). Each inoculum test on a muskmelon cultivar was replicated 7 times. Twenty days after inoculation, wilt incidence was assessed on all plants and muskmelons were classed as resistant, moderately resistant, or moderately susceptible according to the scale of Martyn and Mclaughlin (1983), in which plants with 20% wilting or less were resistant; with 21–50% wilting, moderately resistant; with 51–80% wilting, moderately susceptible; and with more than 80% wilting, highly susceptible. Three cultivars were selected according to this scale: 'Zeinah' as being resistant; 'Ananas', moderately resistant, and 'Amal', moderately susceptible.

Sources of inocula

Meloidogyne javanica and *M. incognita* were obtained from the roots of infected tomato plants. The females were isolated along with their egg masses. The females were identified as to species by morphological characteristics of the perineal pattern (Hartman and Sasser, 1985), while the egg masses were inoculated on susceptible tomato (GS-12) plants to maintain the populations. One population of each nematode species was used in the experiment.

Fusarium oxysporum f. sp. *melonis* was obtained from a wilted muskmelon plant in the Jordan Valley. The pathogenicity of this isolate was tested on the muskmelon cultivar from which it was obtained (Agrios, 1997). For population built-up *Fom* was grown on potato dextrose agar (PDA) for 12 h in an incubator supplemented with fluorescent lighting.

Treatments and data analysis

Thirty-six treatments were completely randomized in a split-plot design with five replicates. Twelve main plots including the non-inoculated control were assigned to the treatments and three sub plots assigned to the selected cultivars (Table 1). The tests were conducted in a growth chamber maintained at 28±2°C, 50–60% relative humidity, with a 16 h day (Salunkhe and Kadam, 1998).

The potting soil consisted of sand, peat moss and perlite 1:1:1 (v:v:v), and was sterilized with methyl bromide at 454 g/1.4 m^3 (Sumner and Johnson, 1973; Khan and Haider, 1991). The soil was placed in 15-cm plastic pots, which were sterilized by dipping in a Benlate solution (12 g/20 l). The pots were placed in the growth chamber, raised from the ground on a bench and spread out to avoid contamination with each other (Ko *et al*., 1997). Ten-day-old muskmelon seedlings of uniform size (first true-leaf stage) were selected and transplanted to the pots.

Eggs of each *Meloidogyne* species were harvested from infected tomato plants using sodium hypochlorite (Barker, 1985). Egg counts in the water suspension were done several times using a 0.5-ml capacity grooved slide and the number of eggs was adjusted to 10^3 eggs ml^{-1}. Ten ml of this suspension was poured into holes made around the stems of the potted muskmelon seedlings. Nematodes were inoculated either at transplanting (ATP) or 14 days after transplanting (14 DAT) and each nematode species was either inoculated alone, or both species were inoculated together into the *Fom*-infected muskmelon plants (Morrell and Bloom, 1981; Shane and Barker, 1986). In treatments where both nematode species were inoculated together, 5 ml of *M. javanica* and 5 ml *M. incognita* suspensions were applied to each pot.

Table 1. Effect of interaction between *Meloidogyne javanica, M. incognita, Fusarium oxysporum* f. sp. *melonis (Fom)* and muskmelon cultivars on plant wilting.

Treatment[a]	Wilting index (0–5)[b]			Wilt increase (%)[b]		
	R	M. R	M. S	R	M. R	M. S
Control	0[c] l	0 l	0 l	0[c]	0	0
Fom 14 DAT	1 k	2 j	3 f–i	20	40	60
Fom 28 DAT	0.8 k	1.9 j	2.6 hi	16	38	52
M. javanica ATP + *Fom* 14 DAT	4 b–e	4.4 a–d	3.8 c–f	80	88	76
M. javanica 14 DAT + *Fom* 14 DAT	4.4 a–d	4.4 a–d	4.4 a–d	88	88	88
M. javanica 14 DAT + *Fom* 28 DAT	5 a	5 a	4.6 a–c	100	100	92
M. incognita ATP + *Fom* 14 DAT	3 f–i	3.8 c–f	3 f–i	60	76	60
M. incognita 14 DAT + *Fom* 14 DAT	3.4 e–h	4 b–e	3 f–i	68	80	60
M. incognita 14 DAT + *Fom* 28 DAT	3 f–i	3 f–i	3.4 e–h	60	60	68
(*M. javanica* + *M. incognita*) ATP + *Fom* 14 DAT	4.4 a–d	5 a	3.6 d–g	88	100	72
(*M. javanica* + *M. incognita*) 14 DAT + *Fom* 14 DAT	4.8 ab	4.6 a–c	4 b–e	96	92	80
(*M. javanica* + *M. incognita*) 14 DAT + *Fom* 28 DAT	4.6 a–c	5 a	5 a	92	100	100

[a] ATP, inoculated at transplanting; 14 DAT, inoculated 14 days after transplanting; 28 DAT, inoculated 28 days after transplanting.
[b] R, resistant; M. R, moderately resistant; M. S, moderately susceptible cultivar.
[c] Mean of 5 replicates. Means within the table followed by the same letter are not significantly different according to Duncan's multiple range test (P= 0.05).

Inoculum of *Fom* was prepared by transferring fungal plugs from a 5-day-old pure colony growing on PDA to 500-ml flasks each containing 100 ml of potato dextrose broth (10 g l^{-1}). Flasks were placed on a shaker operating at 96 rpm and maintained at room temperature. After 5 days, the contents of all flasks were combined and filtered through four layers of cheesecloth. The suspension was adjusted to 10^6 conidia ml^{-1}. A haemocytometer was used to determine inoculum concentration (Waller *et al.*, 1998). One ml of this suspension was applied either 14 days after transplanting (14 DAT) or 28 days after transplanting (28 DAT) (Powell, 1971), without nematodes, or with one or both nematode species. As with the nematodes, the suspensions were applied to holes made in the soil around the plant stems.

The following parameters were determined: (1) shoot length (cm); (2) leaf dry weight (g), determined by drying the leaves in an oven at 60°C for 3 days prior to weighing (Mizrach *et al.*, 1994); (3) the plant wilting index, determined visually using the scale of Abawi and Barker (1984) (0, no symptoms; 1, one or two wilted leaves; 2, half the leaves wilted and beginning to yellow; 3, three-fourths of the leaves wilted, yellow and becoming necrotic; 4, all leaves wilted with lower leaves abscising; and 5, plant dead); (4) the root-galling index (0, no root-galling; 1, 1–10% of roots galled; 2, 11–25%; 3, 26–50%; 4, 51–75% and 5, 76–100% of roots galled); and (5) number of days required for the muskmelons with and without nematodes to start wilting after inoculation with *F. oxysporum* f. sp. *melonis* (Sumner and Johnson, 1973; Abawi and Barker, 1984). In treatments where both nematode species were inoculated, 20 females were randomly dissected from the roots of each plant, the perineal patterns mounted, the species identified (Hartman and Sasser, 1985) and the relative proportion of each species was determined (Khan and Haider, 1991).

Data were subjected to analysis of variance (ANOVA), and means were separated using Duncan's multiple range test at P=0.05 (Steel and Torrie, 1980).

Results

Effect on plant wilting

All three muskmelon cultivars inoculated with *Fom* alone showed a significantly higher plant wilting index than did the non-inoculated control (Table 1). There were no significant differences between *Fom*-inoculated plants 14 DAT and those

inoculated 28 DAT in any of the cultivars.

When muskmelons were treated with *Fom* 14 DAT alone, the increase in wilting was 20% in the resistant cultivar, 40% in the moderately resistant cultivar, and 60% in the moderately susceptible cultivar (Table 1).

Inoculation with *M. javanica* plus *Fom* increased the wilting index significantly in the resistant and moderately resistant cultivars and at all inoculation dates compared with the *Fom*-alone inoculation. The increase in wilting was up to 100% in both resistant and moderately resistant cultivars treated with *M. javanica* 14 DAT + *Fom* 28 DAT.

Inoculation with *M. incognita* plus *Fom* increased the wilting index significantly in the resistant and moderately resistant cultivars and at all inoculation dates, compared with cultivars inoculated with *Fom* alone (Table 1).

Inoculation of *M. javanica* + *M. incognita* + *Fom* significantly increased plant wilting of all cultivars with all treatments compared with muskmelons inoculated with *Fom* alone; except for one treatment on the moderately susceptible cultivar (Table 1). Percent wilting in the three types of cultivars increased to values close to those caused by inoculation with *M. javanica* + *Fom*.

Number of days required for wilting (early expression of disease)

On all three cultivars, taken together, muskmelon plants inoculated with *Fom* alone 14 DAT required an average of 19.3 days after inoculation to exhibit wilting, compared with 26 days after inoculation when *Fom* was inoculated 28 DAT (Table 2). Inoculation of muskmelon plants with *M. javanica* or *M. incognita* ATP caused wilting after 10.6 and 13.3 days respectively, compared with 19.3 days for plants that received *Fom* alone 14 DAT (Table 2). Inoculating muskmelon plants with *M. javanica* and/or *M. incognita* 14 DAT and *Fom* 28 DAT caused wilting within 9 and 11.3 days respectively, compared to 26 days with *Fom* alone 28 DAT.

Effect on foliage dry weight

Inoculation of muskmelon cultivars with *Fom* alone significantly decreased leaf dry weight in the 14 DAT treatments, except in the moderately resistant cultivar, but not in the 28 DAT treatments, as compared with non-inoculated plants (Table 3).

Inoculation with *M. javanica* + *Fom* caused a significant further reduction in the leaf dry weight of all cultivars at all inoculation dates (Table 3). The reduction was up to 77.4% in the resistant cultivar inoculated with *M. javanica* ATP + *Fom*

Table 2. Time required to produce wilting in muskmelon cultivars inoculated with *Fusarium oxysporum* f. sp *melonis (Fom)* with or without *Meloidogyne javanica* and/or *M. incognita*.

Treatment [a]	Days required for wilting [b]			
	R	M. R	M. S	Average
Control	-	-	-	-
Fom 14 DAT	25[c]	20	13	19.3
Fom 28 DAT	29	27	22	26
M. javanica ATP + *Fom* 14 DAT	10	11	11	10.6
M. javanica 14 DAT + *Fom* 14 DAT	20	17	13	16.6
M. javanica 14 DAT + *Fom* 28 DAT	10	9	8	9
M. incognita ATP + *Fom* 14 DAT	17	12	11	13.3
M. incognita 14 DAT + *Fom* 14 DAT	21	17	21	19.6
M. incognita 14 DAT + *Fom* 28 DAT	13	10	11	11.3
(*M. javanica* + *M. incognita*) ATP + *Fom* 14 DAT	12	10	9	10.3
(*M. javanica* + *M. incognita*) 14 DAT + *Fom* 14 DAT	20	18	15	17.6
(*M. javanica* + *M. incognita*) 14 DAT + *Fom* 28 DAT	11	8	8	9

[a] See Table 1.
[b] See Table 1.
[c] Mean of 5 replicates.

14 DAT and 80.2% in the moderately resistant cultivar inoculated with the same mixture.

Inoculation with *M. incognita* + *Fom* also significantly decreased foliage dry weight, but to a less extent than that brought about in plants inoculated with *M. javanica* + *Fom* (Table 3). Inoculation of *M. javanica* simultaneously with *M. incognita* plus *Fom* significantly decreased foliage dry weight in all cultivars at all inoculation dates; except in the moderately resistant cultivar when the fungus was added 28 DAT (Table 3). The percent reduction in foliage dry weight with these treatments was higher than that with *M. incognita* inoculated alone, except for the resistant cultivar inoculated with *M. javanica* + *M. incognita* 14 DAT + *Fom* 14 DAT.

Effect on shoot length

All cultivars inoculated with *Fom* showed a significant reduction in shoot length compared with non-inoculated plants (Table 4). Plants inoculated with *Fom* alone 14 DAT had a significantly shorter average shoot length than plants inoculated with *Fom* 28 DAT.

Inoculation with *M. javanica* + *Fom* caused a further significant decrease in the shoot length compared with plants inoculated with *Fom* alone (Table 4). Inoculation with *M. incognita* + *Fom* significantly reduced shoot length in all cultivars except the moderately resistant and moderately susceptible cultivar inoculated with *M. incognita* 14 DAT+ *Fom* 14 DAT (Table 4) with values that were significantly lower than those recorded with the *M. javanica* inoculations.

Inoculation of *M. javanica* simultaneously with *M. incognita* + *Fom* significantly reduced shoot length in all cultivars at all inoculation dates compared to the *Fom*-alone treatment (Table 4). The percent reductions in shoot length for all cultivars resembled those produced with the *M. javanica* inoculations.

Dominance of root-knot nematode species

There was no significant difference in root galling between nematode inoculation dates, i.e. at transplanting or 14 days after transplanting. *M. javanica* caused severe root galling (galling index 4.75), galling was light to medium with *M. incognita* (galling index 2.6), while with both nematodes inoculated concomitantly the galling index was 3.75.

With all mixed inoculations of *M. javanica* and *M. incognita*, *M. javanica* dominated over *M. incognita* (Table 5). Females of *M. javanica* com-

Table 3. Effect of interaction between *Meloidogyne javanica, M. incognita, Fusarium oxysporum* f. sp. *melonis* (*Fom*) and muskmelon cultivars on foliage dry weight.

Treatment[a]	Foliage dry weight (g)[b]			Reduction in foliage dry weight (%)[b]		
	R	M. R	M. S	R	M. R	M. S
Control	7.80[c] a	4.86 d–f	8.32 a	0	0	0
Fom 14 DAT	5.56 cd	4.66 d–f	6.56 bc	28.7	4.1	21.2
Fom 28 DAT	7.24 ab	3.24 g–j	7.86 a	7.2	33.3	5.5
M. javanica ATP + *Fom* 14 DAT	1.76 k–o	0.96 o	0.96 o	77.4	80.2	88.5
M. javanica 14 DAT + *Fom* 14 DAT	4.14 e–h	3.14 g–j	4.24 e–h	46.9	35.4	49
M. javanica 14 DAT + *Fom* 28 DAT	2.2 j–n	1.56 l–o	4.62 d–f	71.8	67.9	44.5
M. incognita ATP + *Fom* 14 DAT	2.06 j–o	2.8 i–k	1.64 k–o	73.6	42.4	80.3
M. incognita 14 DAT + *Fom* 14 DAT	5.22 de	2.36 j–m	5.76 cd	33	51.4	30.8
M. incognita 14 DAT + *Fom* 28 DAT	5.6 cd	4.2 e–h	6.42 bc	28.2	13.6	22.8
(*M. javanica* + *M. incognita*) ATP + *Fom* 14 DAT	1.3 m–o	1.1 no	1.42 m–o	38.3	77.4	82.9
(*M. javanica* + *M. incognita*) 14 DAT + *Fom* 14 DAT	3.16 g–j	3.12 h–j	4.36 e–g	59.5	64.2	74.6
(*M. javanica* + *M. incognita*) 14 DAT + *Fom* 28 DAT	4.22 e–h	2.66 j–l	3.96 e–i	45.9	45.3	52.4

[a] See Table 1.
[b] See Table 1.
[c] See Table 1.

Table 4. Effect of interaction between *Meloidogyne javanica, M. incognita, Fusarium oxysporum* f. sp. *melonis* (*Fom*) and muskmelon cultivars on shoot length.

Treatment[a]	Shoot length (cm)[b]		
	R	M. R	M. S
Control	412[c] a	360 c	383 b
Fom 14 DAT	232 k	192 mn	228 k
Fom 28 DAT	314 e	248 i	354 d
M. javanica ATP + *Fom* 14 DAT	132 s	57 x	63 w
M. javanica 14 DAT + *Fom* 14 DAT	198 m	142 r	175 op
M. javanica 14 DAT + *Fom* 28 DAT	180 o	170 p	240 j
M. incognita ATP + *Fom* 14 DAT	158 q	98 t	86 uv
M. incognita 14 DAT + *Fom* 14 DAT	270 h	190 n	226 k
M. incognita 14 DAT + *Fom* 28 DAT	288 g	238 j	302 f
(*M. javanica* + *M. incognita*) ATP + *Fom* 14 DAT	90 u	43 y	83 v
(*M. javanica* + *M. incognita*) 14 DAT + *Fom* 14 DAT	194 mn	178 o	192 mn
(*M. javanica* + *M. incognita*) 14 DAT + *Fom* 28 DAT	252 i	218 l	218 l

[a] See Table 1.
[b] See Table 1.
[c] See Table 1.

Table 5. Effect that concomitant inoculation of muskmelon with *Meloidogyne javanica* and *M. incognita*, with or without *Fusarium oxysporum* f. sp. *melonis (Fom)*, has on the number of nematodes sixty days after transplanting.

Treatment[a]	No. of *M. javanica*[b]	No. of *M. incognita*[b]
(*M. javanica* + *M. incognita*) ATP	14	6
(*M. javanica* + *M. incognita*) 14 DAT	12	8
(*M. javanica* + *M. incognita*) ATP + *Fom* 14 DAT	11	9
(*M. javanica* + *M. incognita*) 14 DAT + *Fom* 14 DAT	12	8
(*M. javanica* + *M. incognita*) 14 DAT + *Fom* 28 DAT	15	5

[a] See Table 1.
[b] Number of females (out of 20), based on examination of perineal patterns.

prised from 55 to 75% of nematodes, *M. incognita* females from 25 to 45%. The presence of *Fom* had no effect on the dominance of *M. javanica* over *M. incognita*.

Discussion

Mai and Abawi (1987) stated that the degree to which Fusarium wilt was enhanced in inoculation tests depended on many factors, including the presence of root knot nematodes, the age of the plants at the time of inoculation with one or other pathogen, and the sequence in which the nematode and the wilt pathogen were inoculated. In our study too, *M. javanica* and *M. incognita,* inoculated separately or concomitantly, increased *Fusarium* wilt in all muskmelon cultivars, but the extent of wilt severity enhancement depended on the nematode species, the plant age and the sequence of nematode and fungus inoculation. Later inoculation with *Fom* alone (28 DAT) produced a lower wilt severity and lower plant growth parameters than did earlier inoculation (14 DAT). Latin and Snell (1986) found that wilting of muskmelon seedlings was more severe when *Fom* was inoculated 6 days rather than 11 days after transplanting, which suggests

that in very young seedlings resistance may not yet be expressed

A number of studies reported that the wilt caused by *Fom* was most severe when the nematodes were inoculated 2–4 weeks prior to inoculation with the fungus than when both pathogens were inoculated simultaneously (Powell, 1971; Mai and Abawi, 1987). The present study, however, found that wilt was more severe when *Fom* was inoculated either simultaneously with *M. javanica* and/or *M. incognita*, or 14 days after the nematode(s). Similar results have been reported on watermelon (Sumner and Johnson, 1973; Sultan Al-Tamimi, 1995), squash (Caperton *et al*., 1986), and tomato (Morrell and Bloom, 1981; Abawi and Barker, 1984; El-Sherif and Elwakil, 1991). Also, Moussa (1986), cited in Moussa and Hague (1988), found that when *M. incognita* was inoculated simultaneously with *F. oxysporum* f. sp. *glycines*, soybean resistance to the wilt fungus was broken.

As regards the horticultural parameters, inoculation with the root-knot nematode at transplanting followed by *Fom* 14 days later caused a greater reduction than inoculation with both nematode and fungus simultaneously 14 DAT. This was consistent with Shane and Barker (1986) who found that when *M. incognita* was inoculated 2, 4, 6 and 8 days after transplanting, soybean shoot length, fresh weight and root weight increased with increasing lapse of time between transplanting and inoculation.

Rezk and Fegla (1981) suggested that the *Meloidogyne* species predisposed plants to *F. oxysporum* attack because they caused the sugar and amino acid concentrations in the plants to rise. *F. oxysporum* readily infects the roots by direct penetration, but the wilt can be made more severe by root wounding (Latin and Snell, 1986). The fact that the wilt is more severe in plants inoculated with the root-knot nematodes prior to *F. oxysporum* inoculation supports the general theory that the nematode-wilt interaction is a complex one that involves a modification of the host physiology rather being than a mere wounding due to invasion by juveniles (Webster, 1985). Also, *Meloidogyne* spp. stimulate the production of giant cells in the xylem parenchyma cells adjacent to xylem vessels that act as a nutrient sink (McClure, 1977), and the growth of these cells may facilitate *F. oxysporum* infection of the xylem elements.

Under the conditions of this experiment, *M. javanica* was more severe and dominated over *M. incognita* in all parameters studied. Soil temperature is an important factor in root-knot nematode activity. In this study the soil temperature (25±2°C) was possibly more suitable for *M. javanica* than for *M. incognita*. In Jordan, Abu-Gharbieh (1982) found that the optimal growing temperature for *M. javanica* was 4–5°C higher than that for *M. incognita*.

In general, interaction between simultaneously inoculated *Meloidogyne* species led to mutual inhibition as both species competed with each other for feeding sites. In this study, both nematode species inoculated together increased the wilting index more than *M. incognita* inoculated alone, and this even though the amount of inoculum of *M. javanica* when co-inoculated was only half the amount of inoculum that was given when it was inoculated alone. Possibly *M. javanica* produced more or larger giant cells than *M. incognita*; and in the presence of *Fom* this led to more severe plant wilting. In a similar association, Johnson and Nusbaum (1970) found that reproduction of *M. hapla* was depressed by association with *M. incognita* in susceptible plants, and that this was related to the rapid necrosis of the root tips caused by the invasion of *M. incognita* juveniles. This hypersensitive reaction may similarly have reduced the number of infection sites available for successful colonization by juveniles of *M. hapla*.

Both M. *javanica* and *M. incognita* caused a breakdown of resistance to Fusarium wilt in muskmelon cultivars. A number of other experiments have shown that *M. javanica* and *M. incognita* induce wilting in the cultivars of various crops otherwise resistant to *F. oxysporum* (Powell, 1971; Mai and Abawi, 1987). Caperton *et al.,* (1986) found that resistance of summer squash cultivars to *F. oxysporum* f. sp. *niveum* was dependent on the concentration of the fungal inoculum and the occurrence of root-knot nematodes. Sultan Al-Tamimi (1995) reported 100% wilting when a moderately resistant cultivar of watermelon was inoculated with *M. javanica* in addition to *F. oxysporum* f. sp. *niveum*. Bergeson (1970) reported that the capacity of *M. incognita* to break *Fusarium* wilt resistance varied among cultivars, and that resistance was most

easily broken in cultivars that initially had only partial resistance. These results suggest that although root-knot nematode infection increased the susceptibility of certain cultivars to *Fusarium* wilt, this effect was not uniform throughout a given host species (cited in Caperton *et al*., 1986). It should also be noted that the reaction between root-knot nematode and *Fom* in causing the breakdown of wilt resistance is physiological rather than physical. *M. javanica* possibly produces larger giant cells than *M. incognita*, and since *M. incognita* infection is less significant, plants maintain their resistance to *M. incognita* to a later stage of development, which thus leads to a less severe wilting than with *M. javanica*.

Literature cited

Abawi G.S. and K.R. Barker, 1984. Effects of cultivar, soil temperature, and levels of *Meloidogyne incognita* on root necrosis and Fusarium wilt of tomatoes. *Journal of Phytopathology* 74, 433–438.

Abu-Gharbieh W.I., 1982. Distribution of *Meloidogyne javanica* and *M. incognita* in Jordan. *Nematologica* 28, 34–37.

Agrios G.N. 1997. *Plant Pathology*, 4th edition. Morgan Kaufman publishers, New York, NY, USA, 635 pp.

Armstrong G.M. and J.K. Armstrong, 1978. Formae speciales and races of *Fusarium oxysporum* causing wilt of the cucurbitaceae. *Journal of Phytopathology* 68, 19–28.

Barker K.R., 1985. Nematode extraction and bioassays. In: *An Advanced Treatise on Meloidogyne*, Vol. II, *Methodology*, (K.R. Barker, C.C. Carter, J.N., Sasser, ed.), A Cooperative Publication of the Department of Plant Pathology NCSU and USAID, Raleigh, NC, USA, 19–35.

Bergeson, J.B., VanGundy, S.B. and Thomason, H.J. 1970. Effect of *Meloidogyne javanica* on Rhizosphere microflora and Fusarium wilt of tomato. *Journal of Phytopathology*, 60, 1245–1249.

Caperton C.M., R.D. Martyn and J.L. Starr, 1986. Effect of Fusarium inoculum density and root-knot nematodes on wilt resistance in summer squash. *Journal of Plant Disease* 70, 207–209.

Eisenback J. D., 1985. Interactions among concomitant populations of nematodes. In: *An Advanced Treatise on Meloidogyne*, Vol. I, *Biology and Control*, (J.N. Sasser, C.C. Carter, ed.), A Cooperative Publication of the Department of Plant Pathology NCSU and USAID, Raleigh, NC, USA, 193–213.

El-Sherif A.G. and A.M. Elwakil, 1991. Interaction between *Meloidogyne incognita* and *Agrobacterium tumefaciens* or *Fusarium oxysporum* f. sp. *lycopersici* on tomato. *Journal of Nematology* 23, 239–242.

Freckman D.W. and E.P. Caswell, 1985. The ecology of nematodes in agroecosystems. *Annual Review of Phytopathology* 23, 275–296.

Hartman K.M. and J.N. Sasser, 1985. Identification of *Meloidogyne* species on the basis of differential host tests and perineal pattern morphology. In: *An Advanced Treatise on Meloidogyne,* Vol. II, *Methodology* (K.R. Barker, C.C. Carter, J.N. Sasser, ed.), A Cooperative Publication of the Department of Plant Pathology, NCSU and USAID Raleigh, NC, USA, 69–77

Johnson A.W. and C.J. Nusbaum, 1970. Interactions between *Meloidogyne incognita*, *M. hapla*, and *Pratylenchus brachyurus* in tobacco. *Journal of Nematology* 2, 334–340.

Khan M.W. and S.R. Haider, 1991. Interaction of *Meloidogyne javanica* with different races of *Meloidogyne incognita*. *Journal of Nematology* 23, 298–305.

Ko M.P., D.P. Schmitt and M. Saxby, 1997. Effect of container bases on the spread of *Meloidogyne incognita* in a Hawaiian ornamental nursery. *Journal of Plant Disease* 81, 607–613

Latin R.X. and S.J. Snell, 1986. Comparison of methods for inoculation of muskmelon with *Fusarium oxysporum* f. sp. *melonis*. *Journal of Plant Disease* 70, 297–300.

Mai W.F. and G.S. Abawi, 1987. Interactions among root-knot nematodes and Fusarium wilt fungi on host plants. *Annual Review of Phytopathology* 25, 317–338.

Martyn R.D. and R.J. McLaughlin, 1983. Effects of inoculum concentration on the apparent resistance of watermelons to *Fusarium oxysporum* f. sp. *niveum*. *Journal of Plant Disease* 67, 493–495.

McClure M.A, 1977. *Meloidogyne incognita*: a metabolic sink. *Journal of Nematology* 9, 88–90.

Mizrach A., N. Galili, D.C. Teitel and G. Rosenhouse, 1994. Ultrasonic evaluation of some ripening parameters of autumn and winter-grown 'Galia' melons. *Scientia Horticulturae* 56, 291–297.

Morrell J.J. and J.R. Bloom, 1981. Influence of *Meloidogyne incognita* on Fusarium wilt of tomato at or below the minimum temperature for wilt development. *Journal of Nematology* 13, 57–60.

Moussa E.M. and N.G.M. Hague, 1988. Influence of *Fusarium oxysporum* f. sp. *glycines* on the invasion and development of *Meloidogyne incognita* on soybean. *Revue de Nématologie* 11, 437–439.

Powell N.T., 1971. Interactions between nematodes and fungi in disease complexes. *Annual Review of Phytopathology* 9, 253–274.

Punja Z.K., M. Parker and J.F. Elmhirst, 2001. Fusarium wilt of field-grown muskmelon in British Columbia. *Canadian Journal of Plant Pathology* 23, 403–410.

Rezk M.A. and G.I., Fegla, 1986. Patterns of amino acids and amides in sweet melon plants infected with cucumber mosaic virus and root-knot nematode, *Meloidogyne javanica*. *Alexandria Journal of Agricultural Research* 31, 265–274.

Roberts A.D. and C.W. Boothroyd, 1984. *Fundamentals of Plant Pathology*, 2nd edition. W.H. Freeman & Company, New York, NY, USA, 280 pp.

Sasser J.N., 1980. Root-knot nematodes: a global menace

to crop production. *Journal of Plant Disease* 64, 36–41.
Shane W.W. and K.R. Barker, 1986. Effects of temperature, plant age, soil texture, and *Meloidogyne incognita* on early growth of soybean. *Journal of Nematology* 18, 320–327.
Sikora R.A. and W.W. Carter, 1987. Nematode interaction with fungal and bacterial plant pathogens- fact or fantasy. In: *Vistas on Nematology*. (J.A. Veech,. and D.W. Dickson, ed.), Society of Nematologists, Inc. Hyattsville, MD, USA, 307–312.
Sohi H.S. and S.R. Sharma, 1998. Fungal diseases and their management. In: *Cucurbits* (N.M. Nayar, T.A. More, ed.), Science Publishers, Enfield, NH, USA, 211–223.
Steel R.G.D. and J.H. Torrie, 1980. *Principles and Procedures of Statistics*, 2nd edition. McGraw-Hill Book Company, New York, NY, USA, 633 pp.
Sultan Al-Tamimi A., 1995. *Fusarium Wilt and its Interrelation with the Root-knot Nematode* M. javanica *on Watermelon in Jordan*. MSc Thesis, Faculty of Agriculture, University of Jordan, Amman, Jordan, 67 pp.
Sumner D.R. and A.W. Johnson, 1973. Effect of root-knot nematodes on Fusarium wilt of watermelon. *Journal of Phytopathology* 63, 857–861.
Waller J.M., B.J. Ritchie and M. Holderness, 1998. *Plant Clinic Handbook*. International Mycological Institute, Bakeham Lane, UK, 94 pp.
Webster J.M., 1985. Interaction of *Meloidogyne* with fungi on crop plants. In: *An Advanced Treatise on* Meloidogyne*,* Vol. I, *Biology and Control* (J.N. Sasser, C.C. Carter, ed.), A Cooperative Publication of the Department of Plant Pathology NCSU and USAID, Raleigh, NC, USA, 183–192.
Yamaguchi M., 1983. *World Vegetables*. Ellis Horwood Limited, Publishers, Chichester, UK, 415 pp.

Accepted for publication: October 15, 2004