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Oat, Wheat, and Sorghum Genotype Reactions to *Meloidogyne incognita* and *Meloidogyne javanica*

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Abstract: Meloidogyne spp. are the most economically important species of plant-pathogenic nematodes. Plant resistance and crop rotation are the main nematode management methods. Thus, the objective was to evaluate the resistance of seven wheat genotypes, five oat genotypes, ten sorghum hybrids, and three sorghum–sudangrass genotypes to *Meloidogyne incognita* and *Meloidogyne javanica*. The crops were sowed in pots with an autoclaved substrate. A single plant/pot was left after thinning. The soil was infested with 5,000 eggs of the studied nematodes. Tomato (cv. Rutgers) plants were used as the standard for nematode susceptibility. The evaluations were conducted 60 d after inoculation. Gall and egg-mass indexes were obtained according to a 0–5 scale. Plants with a reproduction factor higher than 1.0 were classified as susceptible (S) and lower than 1.0 as resistant (R). Wheat and oat genotypes did not allow *M. incognita* and *M. javanica* reproduction, proving resistance to these organisms. Sorghum genotypes had different reactions to *M. incognita* and *M. javanica*. The tomato (cv. Rutgers) plants demonstrated the viability of the nematode inoculum for the three crops. The wheat and oat genotypes and the sorghum hybrids 'BRS-610', 'BRS-800', and '307.343' can be used in crop rotation systems for *M. incognita* and *M. javanica* management.

Key words: crop rotation, management, resistance, root-knot nematodes.

Cereals are the most important food source worldwide (FAO, 2014). Wheat is grown mainly to manufacture flour (USDA, 2016). Oat is also cultivated to feed horses or to supply cereals to industries (flakes and flour) and as a green manure or cover in nontillage systems. Sorghum is used for the production of hay and silage and as a crop rotation with winter forages and cereals, as well as soybean (*Glycine max* L. Merr.) and maize (*Zea mays* L.) (Orth et al., 2012). Nematodes can reduce productivity of these important crops (Birchfield, 1983; Pretorius et al., 2014; Marini et al., 2016) and others, such as soybean (Mienie et al., 2002), corn (Till and Lawrence, 2016), cotton (Da Silva et al., 2016; Davis et al., 2016), and sugarcane (Barbosa et al., 2014).

Plant-parasitic nematodes are difficult to control, but management programs including crop rotation with resistant plants (Stapleton et al., 2010) can reduce their populations (Molinari, 2011). However, resistance to nematodes varies between genotypes (Curto et al., 2012; Karajeh et al 2011; Williamson et al., 2013). In Brazil, the oat genotypes 'SI 98102b', 'SI 98103b', and 'SI 98105b' and 24 others were resistant to *M. incognita* (Carneiro et al., 2006). In Italy, six wheat and four oat cv. were resistant to *M. javanica* (Curto et al., 2012). In the USA, the translocation of an *Aegilops ventricosa* gene to the LassiK wheat cv. conferred resistance to virulent and avirulent *M. incognita* and *M. javanica* populations (Williamson et al., 2013). Crop rotation with 'Chapman' oat and maize, in Florida, reduced *M. incognita* populations at the end of the maize harvest (Wang et al., 2004).

Thus, the objective of this study was to evaluate the resistance of wheat, oat, and sorghum genotypes to *M. incognita* and *M. javanica*.

Materials and Methods

Meloidogyne incognita and *M. javanica* pure populations used as inoculum sources were obtained from coffee roots collected in Oswaldo Cruz, São Paulo, Brazil, and 'Magali' pepper collected in Santa Rosa, Rio Grande do Sul, Brazil. The nematodes were identified by the perineal pattern and the isoenzyme electrophoresis of females and multiplied on tomato (*Solanum lycopersicum*, cv. Rutgers) plants.

Experiments were conducted in the greenhouse at maximum temperatures of 24.5°C in test 1 and 28°C in test 2 at the Plant Protection Department (UNESP/FCA—Botucatu, São Paulo State, Brazil). The experimental design was completely randomized with five replications. Seven wheat genotypes ('CD-118', 'CD-104', 'CD-108', 'CD-150', 'BRS-220', 'BRS-Pardela', and 'BRS-Tangará'); five of oat ('URS-21', 'IPR-126', 'URS-Gúria', 'URS-Tarimba', and 'IAC-7'); ten sorghum hybrids (grain sorghum: 'BRS-332', 'BRS-310', 'BRS-330', and 'BRS-308'; forage sorghum: 'BRS-610', 'BRS-655', and 'BRS-700'; and experimental grain sorghum: '307.689', '307.671', and '307.343'); and three sorghum–sudangrass hybrids (forage sorghum 'BRS-802', 'BRS-801', and 'BRS-800') were tested. Two tests with the same methodology were conducted to confirm the results.

Wheat, oat, and sorghum were sowed directly in 2,000 cm^3 polyethylene pots with a 1,800 cm3 autoclaved substrate (120°C for 2 hr) [soil:sand:organic matter (1:2:1)]. One plant/pot was left after thinning. Nematode eggs were extracted (Hussey and Barker, 1973) and 2 ml with 5,000 *M. incognita* or *M. javanica* eggs deposited into two holes around the plants (2.78

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eggs/cm^3 of substrate). Tomato (cv. Rutgers) plants were used to confirm viability of the nematodes.

The evaluations were conducted 60 d after inoculation. Plant roots were washed in running water, weighed, and stained with Floxine B (Daykin and Hussey, 1985). Gall (GI) and egg-mass (EMI) indexes were obtained according to a 0–5 scale as follows: note 0 (without galls or egg masses); grade 1 (1–2 galls or egg masses per root); grade 2 (3–10 galls or egg masses per root); grade 3 (11–30 galls or egg masses per root); grade 4 (31–100 galls or egg masses per root); and grade 5 (more than 100 galls or egg masses per root) (Taylor and Sasser, 1978).

Roots were processed using a blender centrifugal flotation method (Coolen and D'Herde, 1972) using 0.5% sodium hypochlorite solution. The number of eggs and second-stage juveniles (J2) of the nematodes was evaluated using a Peters slide under light microscopy to obtain the reproduction factor (RF = final population/initial population). Plants with RF equal to or higher than 1.0 were classified as susceptible (S) and lower than 1.0 as resistant (R) to the nematodes (Oostenbrink, 1966).

Data from the sorghum experiment were transformed using the following equation: $\sqrt{x} + 0.5$ (1) to meet the presuppositions of variance analysis, analyzed with the SISVAR program, and its averages compared using the Tukey test at 5% probability.

Results

Wheat and oat genotypes did not allow *M. incognita* and *M. javanica* reproduction, proving resistance to these organisms. The GI and EMI of wheat genotypes were zero in test 1, whereas those in test 2 showed values from 0 to 3. However, the RF of *M. incognita* and *M. javanica* was lower than one for all genotypes. This demonstrates that the nematodes penetrated and induced parasitism, but few individuals completed their life cycle. The differences between the two tests could be because of higher temperatures during test 2 (average 24.5°C, test 1, and 28°C, test 2). The similar RFs demonstrate that these wheat and oat genotypes can be planted in areas infested with *M. incognita* and *M. javanica*. The tomato (cv. Rutgers) plants with RF above 12 proved the viability of the inoculum in all experiments with wheat and oat (Table 1).

Sorghum genotypes had different reactions to *M. incognita* and *M. javanica* (Table 2). Hybrids BRS-330, BRS-610, BRS-800, BRS-310, and 307.343 were resistant to *M. incognita* and hybrids BRS-332, BRS-800, 307.343, and BRS-610 were resistant to *M. javanica* in the first and second tests. The BRS-610, BRS-800, and 307.343 sorghum hybrids were simultaneously resistant to *M. incognita* and *M. javanica*. The tomato (cv. Rutgers) plants proved the inoculum viability of these nematodes with RF above 15.

Table 1. Gall (GI) and egg-mass (EMI) indexes, reproduction factor (RF), and reaction (R) of *Meloidogyne incognita* and *Meloidogyne javanica* in wheat and oat genotypes at 60 d after nematode inoculation. Tomato (cv. Rutgers) plants were used as the standard of nematodes susceptibility

		Test 1				Test 2			
Crop	Genotype	GI[a]	EMI[a]	RF[b]	R[c]	GI	EMI	RF	R
Meloidogyne incognita									
Tomato	Rutgers	4.4	3.8	12.2	S	4.4	4.4	15.1	S
Wheat	CD-150	0	0	0	R	1.0	0.8	0.1	R
	CD-108	0	0	0	R	1.4	1.2	0.1	R
	CD-118	0	0	0	R	1.8	1.6	0.2	R
	BRS-220	0	0	0	R	2.6	2.6	0.2	R
	BRS-Tangará	0	0	0	R	2.2	2.2	0.7	R
	CD-104	0	0	0	R	0	0	0	R
	BRS-Pardela	0.4	0.2	0	R	3.0	3.0	0.3	R
Oat	URS-Gúria	0	0	0	R	0	0	0	R
	URS-Tarimba	0	0	0	R	0	0	0	R
	URS-21	0	0	0	R	0	0	0	R
	IAC-7	0	0	0	R	0	0	0	R
	IPR-126	0	0	0	R	0	0	0	R
Meloidogyne javanica									
Tomato	Rutgers	4.4	4.2	13.9	S	4.2	4.0	15.4	S
Wheat	CD-150	0	0	0	R	2.4	2.4	0.1	R
	CD-108	0	0	0	R	2.4	2.2	0.1	R
	CD-118	0	0	0	R	1.8	2.2	0.3	R
	BRS-220	0	0	0	R	1.6	1.6	0.6	R
	BRS-Tangará	0.6	0.4	0	R	1.4	0.8	0.1	R
	CD-104	0	0	0	R	3.4	0.8	0.1	R
	BRS-Pardela	0	0	0	R	2.8	3.0	0.7	R
Oat	URS-Gúria	0	0	0	R	0	0	0	R
	URS-Tarimba	0	0	0	R	0	0	0	R
	URS-21	0	0	0	R	0	0	0	R
	IAC-7	0	0	0	R	0	0	0	R
	IPR-126	0	0	0	R	0	0	0	R

[a] GI and EMI = note 0 (without galls or egg masses); grade 1 (1–2 galls or egg masses per root); grade 2 (3–10 galls or egg masses per root); grade 3 (11–30 galls or egg masses per root); grade 4 (31–100 galls or egg masses per root); and grade 5 (more than 100 galls or egg masses per root).
[b] RF = final population (Pf)/initial population (Pi = 5,000).
[c] R = resistant (RF $<$ 1.0); S = susceptible (RF $\geq$ 1.0).

Discussion

All the wheat and oat genotypes tested in this study could positively contribute to the management of *M. incognita* and *M. javanica* because their genotypes are poor hosts to both nematodes. By contrast, the utility of sorghum hybrids is much more limited and highly dependent on genotypes, with only the hybrids BRS-610, BRS-800, and 307.343 being resistant to both species.

Low multiplication of *M. incognita* and *M. javanica* in wheat genotypes showed that these plants can be cultivated to decrease populations of these nematodes. They may also be cultivated in areas infested with both *M. incognita* and *M. javanica*, which is a common situation in grain crop fields. The variation in the GI and EMI of wheat cv. in tests 1 and 2 can be attributed to the variation in temperature between experiments because temperature affects the life cycle of plant-parasitic nematodes. In Portugal, *Meloidogyne hispanica* development in tomato 'Easypeel' (susceptible) and 'Rossol' (resistant, carrier of the gene *Mi-1.2*) differed at temperatures of

Table 2. Gall (GI) and egg-mass (EMI) indexes, reproduction factor (RF), and reaction (R) of *Meloidogyne incognita* and *Meloidogyne javanica* in sorghum hybrids at 60 d after nematode inoculation. Tomato (cv. Rutgers) plants were used as the standard of nematodes susceptibility

		Test 1				Test 2			
Genotypes	Type[a]	GI[b]	EMI[b]	RF[c]	R[d]	GI	EMI	RF	R
Meloidogyne incognita									
Tomato 'Rutgers'	-	4.4	4.0	15.1 ab	S	5.0	4.6	23.26 a	S
BRS-802	HF*	2.8	4.6	22.6 a	S	3.8	2.4	2.9 b	S
BRS-700	HF	3.8	3.6	13.5 ab	S	1.6	1.4	2.8 b	S
BRS-801	HF*	1.8	1.0	12.2 abc	S	4.0	3.0	4.9 b	S
BRS-308	HG	2.8	3.4	4.6 bcd	S	4.0	4.0	4.3 b	S
307.671	HEG	0.6	0	2.9 cd	S	0.2	0	0 c	R
BRS-655	HF	1.2	0.8	2.3 d	S	0.2	0.2	0.4 c	R
BRS-332	HG	1.0	0.4	2.0 d	S	0.6	0.4	0.8 c	R
307.689	HEG	1.4	0.6	1.3 d	S	0	0	0 c	R
BRS-330	HG	0	0	0.9 d	R	0	0	0.3 c	R
BRS-610	HF	0.6	0.4	0.7 d	R	1.2	0.8	0.4 c	R
BRS-800	HF*	1.2	0	0.5 d	R	0	0	0.1 c	R
BRS-310	HG	0.8	0.2	0.4 d	R	0	0	0.1 c	R
307.343	HEG	1.2	0.6	0.4d	R	0	0	0.1 c	R
C.V. (%)	-			44.6				20.9	
Meloidogyne javanica									
Tomato 'Rutgers'	-	4.2	4.0	15.3 ab	S	5.0	5.0	15.16 a	S
BRS-802	HF*	1.6	3.2	25.5 a	S	2.6	1.6	4.8 cd	S
BRS-801	HF*	2.0	2.2	15.5 ab	S	1.2	0.8	5.0 cd	S
BRS-700	HF	3.2	2.8	13.9 ab	S	3.4	3.4	15.0 b	S
BRS-655	HF	2.0	2.0	8.0 bc	S	3.0	2.8	7.4 c	S
307.689	HEG	1.2	0.2	1.8 c	S	0	0	0 e	R
BRS-330	HG	0.6	0	1.2 c	S	0.2	0	0.7 e	R
307.671	HEG	1.0	0	1.0 c	S	0	0	0 e	R
BRS-332	HG	0.2	0	0.8 c	R	0	0	0.1 e	R
BRS-800	HF*	0	0	0.9 c	R	0.2	0	0.1 e	R
307.343	HEG	1.4	0	0.5 c	R	0	0	0 e	R
BRS-610	HF	1.0	0	0.5 c	R	1.2	0.4	0.1 e	R
BRS-310	HG	1.6	0.2	0.5 c	R	0.6	0.6	1.9 de	S
BRS-308	HG	2.2	4.0	0.3 c	R	2.2	2.0	7.8 c	S
C.V. (%)	-			38.7				26.0	

Mean values of five replications; mean values followed by the same letter per column did not differ by the Tukey test ($P = 0.05$).

[a] HF* = Foraging hybrid (*S. bicolor* × *S. sudanense*); HF = Foraging hybrid, HG = Grain hybrid, HEG = Experimental grain hybrid.

[b] GI and EMI = note 0 (without galls or egg masses); grade 1 (1–2 galls or egg masses per root); grade 2 (3–10 galls or egg masses per root); grade 3 (11–30 galls or egg masses per root); grade 4 (31–100 galls or egg masses per root); and grade 5 (more than 100 galls or egg masses per root).

[c] RF = final population (Pf)/initial population (Pi = 5,000).

[d] R = resistant (RF < 1.0); S = susceptible (RF ≥ 1.0).

15, 20, 25, 30, and 35°C. Penetration of infective juveniles (J2) in the roots was correlated with temperature (Maleita et al., 2012). In Slovenia, temperature also influenced *Meloidogyne ethiopica* reproduction in monocotyledonous and dicotyledonous plants with the reproductive cycle lasting 67, 48, and 36 d at daily mean temperatures of 18.3, 22.7, and 26.3°C, respectively (Strajnar et al., 2011). Similar results were observed in our study as reproduction of *M. incognita* and *M. javanica* occurred in wheat at 28°C, but not at 24.5°C. Suitable temperature occurred in test 2, but the genotypes continued showing resistance, thus demonstrating potential for the management of *Meloidogyne* species.

Oat genotype resistance to *M. incognita* and *M. javanica* agrees with that found for white oat to other *Meloidogyne* species, but with some variability (Karajeh et al., 2011; Carneiro et al., 2006). In Japan, *M. incognita* and *M. arenaria* populations decreased in white oat 'Tachiibuki' grown in naturally infested soil (Tateishi et al., 2011). The resistance of the 'URS Guria' and 'URS Tarimba' genotypes to both nematodes has been reported (Machado et al., 2015). Knowledge about the reaction of each white oat genotype to all important nematode species is necessary because management of nematodes in this crop depends largely on the use of resistant cv.

The variability in the resistance of sorghum genotypes to *Meloidogyne* species agrees with previous reports (Inomoto et al., 2008). The divergent behavior of sorghum hybrids to *M. incognita* and *M. javanica* demonstrates the importance of knowing the hybrid reaction before using them in crop fields (Inomoto et al., 2008). The reactions of forage and grain sorghum to *M. incognita* and *M. javanica* differed in our study. The grain sorghums were, mostly, inadequate hosts to both *Meloidogyne* species as found for other sorghum cv. (Inomoto et al., 2008). The reduction of *M. incognita* populations in the USA in sorghum 'Green Grazer V' and 'KS585' was higher than that in soybean used as crop rotation with potato (Everts et al., 2006). In Brazil, sorghum 'Super Dolce 10' was resistant to *M. incognita*, and it is an option for crop rotation system in infested areas (Curto et al., 2012). These results are promising because resistant sorghum can be used in rotation or as a succession crop to manage these nematodes. These plants offer economic returns because sorghum is a good option for a summer crop.

In summary, all wheat and oat genotypes tested and the sorghum hybrids 'BRS-610', 'BRS-800', and '307.343' were resistant to *M. incognita* and *M. javanica* and, therefore, can be used for nematode management in rotation and succession systems in areas that are infested with either one or both species.

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