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New resistance sources to root-knot nematode in *Capsicum* pepper

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ABSTRACT

Thirty seven pepper genotypes, *Capsicum chinense*, *C. annuum* and *C. frutescens*, were characterized for resistance to three root-knot nematode species (*Meloidogyne javanica*, *M. incognita* race 1 and *M. enterolobii*) aiming to find potential resistance sources to be used in breeding programs. Three experiments were carried out, in 2013, 2014 and 2016, in a greenhouse, in randomized block design and six replicates, one plant/pot. Data were submitted to analysis of variance and average clustering. All evaluated pepper genotypes were resistant or immune to *M. javanica*. For *M. incognita* race 1, all accessions of *C. frutescens*, evaluated in the first experiment, were resistant, whereas the six accessions of *C. chinense* were susceptible. For *M. incognita*, all genotypes of *C. chinense* and *C. annuum*, evaluated in the second experiment, were resistant. In the third experiment, evaluating *C. annuum* genotypes, we verified that most were susceptible to *M. incognita* race 1; genotypes CNPH 30118 and CNPH 6144 were resistant, though. *M. enterolobii*, which is the most aggressive species, with few resistance sources described, showed a tendency of greater degree of resistance in *C. chinense* and *C. frutescens*. Although most of the evaluated genotypes were susceptible, significant differences were observed regarding the degree of susceptibility. The main contribution of this study was the identification of a genotype resistant to *M. enterolobii*, cultivar BRS Nandaia, which can be used in breeding programs.

Keywords: *Capsicum* spp., *Meloidogyne javanica*, *M. incognita* race 1, *M. enterolobii*.

RESUMO

Novas fontes de resistência aos nematoides-das-galhas em pimenta *Capsicum*

Este trabalho teve como objetivo a caracterização de 37 genótipos de pimenta das espécies *Capsicum chinense*, *C. annuum* e *C. frutescens*, quanto à resistência a três espécies de nematoides-das-galhas *Meloidogyne javanica*, *M. incognita* raça 1 e *M. enterolobii*, visando prospectar potenciais fontes de resistência para serem utilizadas no melhoramento. Para isso, foram realizados três experimentos em 2013, 2014 e 2016, em casa de vegetação, com delineamento em blocos casualizados com seis repetições em parcelas constituídas por uma planta/vaso. Os dados foram submetidos a análises de variância e de agrupamento de médias. Todos genótipos de pimenta avaliados foram resistentes ou imunes a *M. javanica*. Para *M. incognita* raça 1, todos genótipos de *C. frutescens* avaliados no primeiro experimento foram resistentes, enquanto que os seis genótipos de *C. chinense* foram suscetíveis. Ainda, para *M. incognita*, todos genótipos de *C. chinense* e *C. annuum* avaliados no segundo experimento, foram resistentes. No terceiro experimento, com genótipos de *C. annuum*, a maioria foi suscetível a *M. incognita* raça 1, mas os genótipos CNPH 30118 e CNPH 6144 foram resistentes. Quanto a *M. enterolobii*, que é a espécie mais agressiva, com poucas fontes de resistência descritas, houve uma tendência de maior grau de resistência em *C. chinense* e *C. frutescens*. Mas, apesar de a maioria dos genótipos avaliados serem suscetíveis, foram observadas diferenças significativas quanto ao grau de suscetibilidade. A principal contribuição deste trabalho foi a identificação de um genótipo resistente a *M. enterolobii*, a cultivar BRS Nandaia, sendo possível explorar esta fonte de resistência no melhoramento genético.

Palavras-chave: *Capsicum* spp., *Meloidogyne javanica*, *M. incognita* raça 1, *M. enterolobii*.

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Pepper is grown in all Brazilian regions; however, no statistical analysis accurately quantifies the economic importance of this crop, since much of the production is sold in local and outdoor markets. One of the biggest

problems for pepper cultivation is the root-knot nematode. These pathogens damage the plant root system and transport of water and nutrients, limiting its productivity (Kiewnick *et al.*, 2009; Chaudhary & Kaul, 2012).

Worldwide, the root-knot nematodes species which cause the most damages to pepper are *Meloidogyne incognita*, *M. arenaria* and *M. javanica*, found mainly in warm climates, especially in tropical and subtropical regions (Mashela &

Pofu, 2012; Hussain *et al.*, 2013).

Another nematode species which has impaired vegetable production is *M. enterolobii*. This species was originally found in guava plants in 2001 in Pernambuco and Bahia States, and since then it is one of Brazilian producers' concern. In vegetables, this species was reported, for the first time, in São Paulo State, parasitizing bell pepper cv. 'Silver' rootstocks and 'Andréa' and 'Débora' tomato plants, resistant to *M. incognita* and *M. javanica* (Carneiro *et al.*, 2006). Preliminary studies show that peppers of the genus *Capsicum* are more susceptible to *M. enterolobii* comparing to other species of root-knot nematodes (Kiewnick *et al.*, 2009; Pinheiro *et al.*, 2015). On the other hand, some reports on different levels of susceptibility or even resistance in pepper can be found in literature (Oliveira, 2007; Melo *et al.*, 2011; Pinheiro *et al.*, 2013; Gonçalves *et al.*, 2014).

Resistance to root-knot nematodes has been associated with independent dominant genes for resistance to *M. incognita*, *M. arenaria* and *M. javanica*: *N*, *Me1*, *Me2*, *Me3*, *Me4*, *Me5*, *Me6*, *Me7*, *Mech1* and *Mech2*. Some of these genes, such as *Me1*, *Me3* and *Me7* are considered thermo-stable and effective against a wide range of *Meloidogyne* species, including *M. incognita*, *M. arenaria* and *M. javanica* (Djian-Caporalino *et al.*, 2011).

Due to high relevance of nematodes for pepper crop, the characterization of potential genotypes to become new cultivars or to be used for crossings to add resistance factor to other characters of agronomic importance is crucial. Therefore, this study aimed to characterize pepper genotypes in relation to resistance against three root-knot nematode species, allowing to select resistant inbred lines to be released as cultivars and/or as potential resistance sources for breeding programs.

MATERIAL AND METHODS

The experiments were carried out from April to July, 2013 – 2016, and from October to January, 2014, in Distrito Federal, Brazil, in greenhouses.

In 2013, ten pepper genotypes were evaluated, considering six inbred lines of *C. chinense* 'Habanero' variety group (CNPH 15.320, CNPH 15.330, CNPH 15.332, CNPH 15.348, CNPH 15.363 and CNPH 15.367) and four inbred lines of Malagueta (*C. frutescens*) (CNPH 20.334, CNPH 20.699, CNPH 20.700 and CNPH 20.701). In 2014, five *C. annuum* genotypes were evaluated, being one bell pepper genotype (bell pepper cv. Tico) and four Jalapeño pepper types ('BRS Sarakura', CNPH 25.296, CNPH 25.324 and CNPH 25.313), and more six *C. chinense* sweet pepper types (CNPH 972, CNPH 3447), Habanero ('BRS Juruti', 'BRS Nandaia') and Biquinho (CNPH 35.114 and CNPH 35.122). In 2016, 16 *C. annuum* genotypes belonging to variety groups Cayenne (CNPH 0029), Jalapeño (CNPH 4547, CNPH 30112, CNPH 30118, CNPH 30147, CNPH 30159, CNPH 30183, CNPH 30245) and Paprika (CNPH 6127, CNPH 6128, CNPH 6132, CNPH 6142, CNPH 6143, CNPH 6144, CNPH 6625, CNPH 6628). These were characterized in relation to *M. javanica*, *M. incognita* race 1 and *M. enterolobii*.

Bell pepper 'Magali' and 'Rutgers' tomato plant (*Solanum lycopersicum*) were used as controls in 2013, as susceptibility standards and the 'Snooker' bell pepper rootstock as resistance standard. In 2014, the same controls and tomato plants 'HF1-181' and 'Nemadoro' (resistant) and pepper genotype CNPH 3287 (*C. chinense*) (susceptible) were used. In 2016, 'Rutgers' and 'TH 01' tomato plants were used for standards of susceptibility and resistance, respectively.

The experiments were conducted in greenhouse in randomized block design in factorial scheme for each year, with six replicates, considering that the experimental unit consisted of one plant per pot with 1.5 liters sterilized substrate autoclaved at 121°C for 60 min. Sowings were done on April 24, 2013, October 23, 2014 and April 18, 2016. About 20 days after sowing, plants were inoculated with suspension of 5,000 eggs and eventual second stage juveniles (J2) of each isolated species, in 5 mL water distributed around the

stem base.

At 75 days after inoculation, eggs and J2 were extracted from the root system of the plants according to methodology of Boneti & Ferraz (1981). The following variables were evaluated: egg mass index (IMO): the root system was washed in running water, stained with Phloxin B solution 0.5 g/L water for 15 minutes. Then, the authors counted the number of egg masses of nematodes using a stereoscope microscope. IMO in roots was obtained according to Taylor & Sasser (1978), using a note scale from 0 to 5, in which 0 is related to roots without egg masses; 1 is related to 1 to 2 egg masses; 2 corresponds to a range from 3 to 10 egg masses; 3, from 11 to 30 egg masses; 4, from 31-100 egg masses and 5 corresponds to more than 100 egg masses/root system. The authors also evaluated gall index (IG), which is the number of galls in each root system in each plant/replicate. IG in roots was represented by the scale from 0 to 5, according to Taylor & Sasser (1978), replacing the quantification of egg masses by galls and then assigning the grades. To evaluate the number of eggs per gram of roots (eggs/g), roots were washed, dried at room temperature for five hours and weighed before being processed according to Bonetti & Ferraz (1981), counting the number of eggs of each plant divided by the weight, considering that in the experiment of 2013 this character was not evaluated. Reproduction factor (FR) was obtained dividing the final and initial population densities ($FR = Pf/Pi$), considering zero the immune value (I), lower than 1 resistant (R) and higher than 1 susceptible (S) (Oostenbrink, 1966).

Data eggs/g roots and FR were transformed in $\sqrt{x+0.5}$ to meet the normal distribution. All data were submitted to analysis of individual and joint variance for three species of nematodes in each year, and average clustering by Scott-Knott, using Genes software (Cruz, 2013).

RESULTS AND DISCUSSION

Significant interaction between

Table 1. Evaluation of pepper accessions for resistance to root-knot nematode, 2013. Brasília, Embrapa Hortaliças, 2019.

Genotypes	Species	Type	IG	IMO	FR/reaction
			<i>Meloidogyne javanica</i>		
CNPH 15.320	<i>C. chinense</i>	Habanero	0.50 c	0.50 c	0.05 b / R
CNPH 15.330	<i>C. chinense</i>	Habanero	0.67 c	0.67 c	0.05 b / R
CNPH 15.332	<i>C. chinense</i>	Habanero	0.33 c	0.33 c	0.18 b / R
CNPH 15.348	<i>C. chinense</i>	Habanero	0.33 c	0.33 c	0.17 b / R
CNPH 15.363	<i>C. chinense</i>	Habanero	1.00 b	1.00 b	0.12 b / R
CNPH 15.367	<i>C. chinense</i>	Habanero	0.50 c	0.50 c	0.17 b / R
CNPH 20.334	<i>C. frutescens</i>	Malagueta	1.00 b	1.00 b	0.17 b / R
CNPH 20.699	<i>C. frutescens</i>	Malagueta	1.00 b	1.00 b	0.08 b / R
CNPH 20.700	<i>C. frutescens</i>	Malagueta	0.33 c	0.50 c	0.05 b / R
CNPH 20.701	<i>C. frutescens</i>	Malagueta	0.50 c	0.50 c	0.08 b / R
Magali	<i>C. annuum</i>	Bell pepper	1.00 b	1.00 b	0.17 b / R
Snooker	<i>C. annuum</i>	Bell pepper	0.50 c	0.50 c	0.10 b / R
Rutgers	<i>S. lycopersicum</i>	Tomato	4.50 a	5.00 a	54.38 a / S
Average	-	-	0.93	0.98	4.28
CV (%)	-	-	19.13	18.76	37.28
CVg/CV	-	-	1.62	1.75	3.75
<i>Meloidogyne incognita</i> race 1					
CNPH 15.320	<i>C. chinense</i>	Habanero	3.50 a	3.83 b	7.55 c / S
CNPH 15.330	<i>C. chinense</i>	Habanero	3.17 b	4.17 b	10.85 c / S
CNPH 15.332	<i>C. chinense</i>	Habanero	3.00 b	3.83 b	9.28 c / S
CNPH 15.348	<i>C. chinense</i>	Habanero	3.67 a	4.83 a	17.75 b / S
CNPH 15.363	<i>C. chinense</i>	Habanero	3.67 a	4.33 b	6.18 c / S
CNPH 15.367	<i>C. chinense</i>	Habanero	2.00 c	2.33 d	3.20 d / S
CNPH 20.334	<i>C. frutescens</i>	Malagueta	1.00 d	1.00 e	0.12 e / R
CNPH 20.699	<i>C. frutescens</i>	Malagueta	0.83 d	0.83 e	0.10 e / R
CNPH 20.700	<i>C. frutescens</i>	Malagueta	1.17 d	1.17 e	0.37 e / R
CNPH 20.701	<i>C. frutescens</i>	Malagueta	1.00 d	1.00 e	0.07 e / R
Magali	<i>C. annuum</i>	Bell pepper	2.83 b	3.17 c	6.23 c / S
Snooker	<i>C. annuum</i>	Bell pepper	0.17 e	0.17 f	0.02 e / R
Rutgers	<i>S. lycopersicum</i>	Tomato	4.17 a	5.00 a	25.60 a / S
Average	-	-	2.32	2.74	6.71
CV (%)	-	-	9.99	9.98	34.35
CVg/CV	-	-	2.68	3.04	1.80
<i>Meloidogyne enterolobii</i>					
CNPH 15.320	<i>C. chinense</i>	Habanero	3.00 b	4.33 b	2.55 c / S
CNPH 15.330	<i>C. chinense</i>	Habanero	3.33 b	4.67 a	4.23 b / S
CNPH 15.332	<i>C. chinense</i>	Habanero	3.50 b	5.00 a	5.03 b / S
CNPH 15.348	<i>C. chinense</i>	Habanero	3.17 b	4.17 b	3.33 b / S
CNPH 15.363	<i>C. chinense</i>	Habanero	2.83 c	3.83 c	5.32 b / S
CNPH 15.367	<i>C. chinense</i>	Habanero	2.67 c	3.50 c	1.83 c / S
CNPH 20.334	<i>C. frutescens</i>	Malagueta	3.00 b	3.83 c	1.63 c / S
CNPH 20.699	<i>C. frutescens</i>	Malagueta	2.67 c	3.17 c	1.95 c / S
CNPH 20.700	<i>C. frutescens</i>	Malagueta	2.83 c	4.00 c	1.27 c / S
CNPH 20.701	<i>C. frutescens</i>	Malagueta	2.50 c	3.33 c	1.17 c / S
Magali	<i>C. annuum</i>	Bell pepper	4.67 a	4.83 a	4.40 b / S
Snooker	<i>C. annuum</i>	Bell pepper	2.33 c	4.17 b	4.70 b / S
Rutgers	<i>S. lycopersicum</i>	Tomato	5.00 a	5.00 a	34.50 a / S
Average	-	-	3.19	4.14	5.53
CV (%)	-	-	8.31	6.70	22.32
CVg/CV	-	-	1.20	0.93	2.47

IG (gall index) and IMO (egg mass) according to Taylor & Sasser (1978) where 0) roots without egg mass and/or galls; 1) roots with 1 to 2 egg masses and/or galls; 2) roots with 3 to 10 egg masses and/or galls; 3) roots with 11 to 30 egg masses and/or galls; 4) roots with 31 to 100 egg masses and/or galls; 5) roots with over 100 egg masses and/or galls. FR/reaction (reproduction factor, final population/initial population) according to Oostenbrink (1966) where I= immune (FR= 0); R= resistant (FR<1) and S= susceptible (FR>1). Averages followed by same letters do not differ from each other, Scott-Knott test ($p<0.05$). CV= coefficients of environmental variation. CVg/CV= genotypic and phenotypic coefficients of variation ratio.

genotypes and nematode species was verified in the three experiments (2013, 2014 and 2016), showing that genotype response to resistance level was different depending on the evaluated nematode species. Significant differences were noticed in all analyses of individual variance ($P < 0.05$) for all characters in both experiments (data not shown).

Coefficients of environmental variation were higher for number of eggs per gram of roots (eggs/g), showing that this character is strongly influenced by environment, and that observations which were carried out using this variable would be unreliable (in the first experiment this character was not evaluated). For other characters,

coefficients of variation showed lower value, and the coefficients of genotypic and environmental variation ratio (CVg/CV) were higher than the unit for most evaluated characters in the three experiments (Tables 1, 2 and 3). This result shows predominance of genetic variation, surpassing the environmental variation and, as a consequence, the

Table 2. Reaction of pepper species to root-knot nematode in 2014. Brasília, Embrapa Hortaliças, 2019.

Genotypes	Species	Type	IG	IMO	Eggs/g	FR/Reaction
					<i>M. javanica</i>	
Bell pepper cv. Tico	<i>C. annuum</i>	Bell pepper	1.02 c	1.02 b	13.90 b	0.02 b / R
BRS Sarakura	<i>C. annuum</i>	Jalapeño	1.00 c	1.00 b	3.72 b	0.01 b / R
CNPH 25.296	<i>C. annuum</i>	Jalapeño	1.00 c	1.00 b	24.04 b	0.04 b / R
CNPH 25.324	<i>C. annuum</i>	Jalapeño	1.00 c	1.00 b	42.36 b	0.06 b / R
CNPH 25.313	<i>C. annuum</i>	Jalapeño	1.02 c	1.02 b	13.64 b	0.03 b / R
CNPH 972	<i>C. chinense</i>	Sweet pepper	1.00 c	1.00 b	3.31 b	0.01 b / R
CNPH 3447	<i>C. chinense</i>	Sweet pepper	1.00 c	1.00 b	8.50 b	0.04 b / R
BRS Juruti	<i>C. chinense</i>	Habanero	1.02 c	1.02 b	11.69 b	0.05 b / R
BRS Nandaia	<i>C. chinense</i>	Habanero	1.00 c	1.00 b	23.06 b	0.02 b / R
CNPH 35.114	<i>C. chinense</i>	Pepper pout	1.00 c	1.00 b	2.88 b	0.01 b / R
CNPH 35.122	<i>C. chinense</i>	Pepper pout	1.00 c	1.00 b	4.52 b	0.02 b / R
Magali	<i>C. annuum</i>	Bell pepper	1.02 c	1.02 b	21.68 b	0.06 b / R
Snooker	<i>C. annuum</i>	Rootstock	1.00 c	1.00 b	22.62 b	0.03 b / R
HF1-181	<i>S. lycopersicum</i>	Tomato	1.02 c	1.02 b	6.86 b	0.03 b / R
CNPH 3287	<i>C. chinense</i>	Sweet pepper	1.00 c	1.00 b	41.40 b	0.05 b / R
Rutgers	<i>S. lycopersicum</i>	Tomato	4.98 a	3.83 a	1186.44 a	5.93 a / S
Nemadoro	<i>S. lycopersicum</i>	Tomato	1.33 b	1.17 b	7.35 b	0.04 b / R
Average	-	-	1.26	1.18	84.58	0.38
CV%	-	-	1.96	16.9	84.83	16.41
CVg/CV	-	-	4.67	4.03	1.82	3.74
<i>M. incognita</i> race 1						
Bell pepper cv. Tico	<i>C. annuum</i>	Bell pepper	1.33 c	1.83 b	56.83 b	0.10 d / R
BRS Sarakura	<i>C. annuum</i>	Jalapeño	1.00 c	1.00 c	26.84 b	0.06 d / R
CNPH 25.296	<i>C. annuum</i>	Jalapeño	1.67 b	1.83 b	102.51 b	0.15 d / R
CNPH 25.324	<i>C. annuum</i>	Jalapeño	2.33 b	2.50 b	403.55 b	0.22 d / R
CNPH 25.313	<i>C. annuum</i>	Jalapeño	1.50 c	2.17 b	167.11 b	0.18 d / R
CNPH 972	<i>C. chinense</i>	Sweet pepper	2.33 b	2.11 b	136.79 b	0.57 c / R
CNPH 3447	<i>C. chinense</i>	Sweet pepper	1.33 c	1.17 c	110.36 b	0.39 c / R
BRS Juruti	<i>C. chinense</i>	Habanero	1.33 c	1.33 c	47.13 b	0.14 d / R
BRS Nandaia	<i>C. chinense</i>	Habanero	1.00 c	1.00 c	308.02 b	0.08 d / R
CNPH 35.114	<i>C. chinense</i>	Pepper pout	2.00 b	1.67 b	175.84 b	0.19 d / R
CNPH 35.122	<i>C. chinense</i>	Pepper pout	2.33 b	2.00 b	338.47 b	0.56 c / R
Magali	<i>C. annuum</i>	Bell pepper	1.00 c	1.00 c	142.83 b	0.23 d / R
Snooker	<i>C. annuum</i>	Rootstock	1.00 c	1.00 c	47.38 b	0.07 d / R
HF1-181	<i>S. lycopersicum</i>	Tomato	1.00 c	1.00 c	19.79 b	0.09 d / R
CNPH 3287	<i>C. chinense</i>	Sweet pepper	1.50 c	1.17 c	302.81 b	1.18 b / S
Rutgers	<i>S. lycopersicum</i>	Tomato	5.00 a	4.33 a	1124.24 a	5.18 a / S
Nemadoro	<i>S. lycopersicum</i>	Tomato	0.67 c	0.67 c	56.83 b	0.13 d / S
Average	-	-	1.67	1.63	207.89	0.57
CV%	-	-	39.12	37.31	77.78	22.54
CVg/CV	-	-	1.60	1.51	0.80	2.22

Table 2 continuation

Genotypes	Species	Type	IG	IMO	<i>M. enterolobii</i>	
					Eggs/g	FR/Reaction
Bell pepper cv. Tico	<i>C. annuum</i>	Bell pepper	5.00 a	4.21 b	1265.77 b	4.65 a / S
BRS Sarakura	<i>C. annuum</i>	Jalapeño	4.00 b	4.00 b	1423.75 b	4.46 a / S
CNPH 25.296	<i>C. annuum</i>	Jalapeño	4.00 b	3.67 c	3279.68 a	6.34 a / S
CNPH 25.324	<i>C. annuum</i>	Jalapeño	5.00 a	4.20 b	3906.20 a	6.16 a / S
CNPH 25.313	<i>C. annuum</i>	Jalapeño	5.00 a	5.00 a	4874.49 a	11.42 a / S
CNPH 972	<i>C. chinense</i>	Sweet pepper	4.67 a	4.17 b	3231.96 a	8.61 a / S
CNPH 3447	<i>C. chinense</i>	Sweet pepper	3.67 b	3.67 c	3107.33 a	9.81 a / S
BRS Juruti	<i>C. chinense</i>	Habanero	3.00 c	3.00 d	878.58 b	2.44 b / S
BRS Nandaia	<i>C. chinense</i>	Habanero	2.67 c	2.67 d	809.31 b	0.50 b / R
CNPH 35.114	<i>C. chinense</i>	Pepper pout	3.46 b	3.46 c	2682.74 a	7.15 a / S
CNPH 35.122	<i>C. chinense</i>	Pepper pout	4.50 a	4.17 b	1652.94 a	8.53 a / S
Magali	<i>C. annuum</i>	Bell pepper	4.83 a	4.50 b	1065.85 b	2.87 b / S
Snooker	<i>C. annuum</i>	Rootstock	5.00 a	4.00 d	788.27 b	1.88 b / S
HF1-181	<i>S. lycopersicum</i>	Tomato	5.00 a	5.00 a	2143.17 a	10.08 a / S
CNPH 3287	<i>C. chinense</i>	Sweet pepper	3.33 b	3.33 c	1460.71 b	5.31 b / S
Rutgers	<i>S. lycopersicum</i>	Tomato	5.00 a	5.00 a	864.28 b	7.83 a / S
Nemadoro	<i>S. lycopersicum</i>	Tomato	5.00 a	4.00 b	334.21 b	3.97 b / S
Average	-	-	4.30	4.00	1986.43	6.00
CV%	-	-	14.82	17.48	53.19	40.89
CVg/CV	-	-	2.22	1.80	0.64	0.87

IG (gall index) and IMO (egg mass) according to Taylor & Sasser (1978) where 0) roots without egg mass and/or galls; 1) roots with 1 to 2 egg masses and/or galls; 2) roots with 3 to 10 egg masses and/or galls; 3) roots with 11 to 30 egg masses and/or galls; 4) roots with 31 to 100 egg masses and/or galls; 5) roots with over 100 egg masses and/or galls. Eggs/g= number of eggs per gram of roots. FR/reaction (reproduction factor, final population/initial population) according to Oostenbrink (1966) where I= immune (FR= 0); R= resistant (FR<1) and S= susceptible (FR>1). Averages followed by same letters do not differ from each other, Scott-Knott test ($p<0.05$). CV= coefficients of environmental variation. CVg/CV= genotypic and phenotypic coefficients of variation ratio.

reliability of the estimates.

The first set of genotypes (2013) showed resistance to *M. javanica*. For *M. incognita* race 1, *C. frutescens* genotypes were resistant, whereas *C. chinense* genotypes were classified as susceptible. For *M. enterolobii*, all evaluated genotypes, including controls used as resistant to other root-knot species, showed susceptibility. However, Habanero pepper inbred lines CNPH 15.320 and CNPH 15.367 and the set of 'Malagueta' inbred lines showed lower FR being classified as resistant (Table 1).

All genotypes belonging to the second evaluated set (2014) were resistant to *M. javanica* and *M. incognita* race 1. For *M. enterolobii* almost all genotypes were susceptible, except pepper cultivar Habanero BRS Nandaia which showed the lowest indexes of galls (IG) and egg masses (IMO), statistically grouped with Habanero BRS Juruti, classified as resistant, with

FR 0.50 (Table 2).

For the third set of genotypes evaluated in this experiment (2016), belonging to *C. annuum* species, all showed resistance or immunity to *M. javanica*. For *M. incognita* race 1, almost all genotypes were susceptible, except CNPH 30118 (Jalapeño type) and CNPH 6144 (Paprika type). In relation to *M. enterolobii*, all genotypes were susceptible; genotypes CNPH 0029 (Cayenne type), CNPH 4547 (Jalapeño), CNPH 30112 (Jalapeño), CNPH 6132 (Paprika) and CNPH 6144 (Paprika) showed lower FR. Genotype CNPH 6144 also showed lower values for IG and IMO (Table 3). Different reactions of these genotypes to nematodes *M. javanica* and *M. incognita* were possibly because of the specificity of some *M* genes and resistance in *C. annuum* (Djian-Caporalino *et al.*, 2011).

Pinheiro *et al.* (2013) evaluated 50 *C. chinense* genotypes for *M. enterolobii* and verified that all were susceptible,

variation in relation to FR was verified, though, considering that 18 of these genotypes showed lower FR (1.27 to 2.83).

Similarly, Pinheiro *et al.* (2014) evaluated four pepper genotypes belonging to each one of *C. chinense*, *C. frutescens* and *C. baccatum* species in relation to the reaction to the same nematode species evaluated in this study and verified that *C. chinense* and *C. baccatum* genotypes were susceptible to *M. javanica* and *M. incognita* race 1, whereas *C. frutescens* genotypes were resistant. For *M. enterolobii*, all genotypes were susceptible, with lower FR for *C. frutescens*, in accordance with this study (Table 1).

Oliveira (2007), evaluating different *Capsicum* species, observed that all nine *C. chinense* genotypes were susceptible to *M. enterolobii*, with FR lower than the ones obtained in *C. annuum*, though. He adds that the only *C. frutescens* genotype which was evaluated was

considered resistant, FR=0.61. Melo *et al.* (2011) also verified lower reproduction indexes for *C. chinense* comparing with *C. annuum*, with higher tolerance of *C. chinense* accessions BGH-433 and BGH-4285, and also

C. annuum accessions PIM-031, PIX-022I-31-07-02 and PIX-022I-31-13-01, FR= 1.20, 1.00, 1.00, 1.20 and 0.70, respectively.

In a similar study, Gonçalves *et al.* (2014) evaluated 12 *C. annuum*

accessions, 11 *C. chinense*, 10 *C. baccatum*, and 6 *C. frutescens* for resistance to *M. enterolobii*. FR averages for the studied species showed the following sequence: *annuum* (17.95) > *C. baccatum* (14.19) > *C. chinense*

Table 3. Reaction of pepper species to root-knot nematode in 2016. Brasília, Embrapa Hortaliças, 2019.

Genotypes	Species	Type	IG	IMO	Eggs/g		FR/reaction
					<i>M. javanica</i>		
CNPH 0029	<i>C. annuum</i>	Cayenne	1.00 b	1.00 b	34.48 b		0.01 b / R
CNPH 4547	<i>C. annuum</i>	Jalapeño	1.00 b	1.00 b	105.26 b		0.06 b / R
CNPH 30112	<i>C. annuum</i>	Jalapeño	1.00 b	1.00 b	82.46 b		0.03 b / R
CNPH 30118	<i>C. annuum</i>	Jalapeño	1.00 b	1.00 b	0.00 b		0.00 b / I
CNPH 30147	<i>C. annuum</i>	Jalapeño	1.00 b	1.00 b	9.11 b		0.01 b / R
CNPH 30159	<i>C. annuum</i>	Jalapeño	1.00 b	1.00 b	0.00 b		0.00 b / I
CNPH 30183	<i>C. annuum</i>	Jalapeño	1.00 b	1.00 b	58.25 b		0.06 b / R
CNPH 30245	<i>C. annuum</i>	Jalapeño	1.00 b	1.00 b	0.00 b		0.00 b / I
CNPH 6127	<i>C. annuum</i>	Paprika	1.00 b	1.00 b	4.45 b		0.01 b / R
CNPH 6128	<i>C. annuum</i>	Paprika	1.00 b	1.00 b	8.70 b		0.01 b / R
CNPH 6132	<i>C. annuum</i>	Paprika	1.00 b	1.00 b	19.79 b		0.04 b / R
CNPH 6142	<i>C. annuum</i>	Paprika	1.00 b	1.00 b	27.14 b		0.04 b / R
CNPH 6143	<i>C. annuum</i>	Paprika	1.00 b	1.00 b	103.70 b		0.02 b / R
CNPH 6144	<i>C. annuum</i>	Paprika	1.00 b	1.00 b	40.06 b		0.07 b / R
CNPH 6625	<i>C. annuum</i>	Paprika	1.00 b	1.00 b	29.18 b		0.04 b / R
CNPH 6628	<i>C. annuum</i>	Paprika	1.00 b	1.00 b	19.86 b		0.03 b / R
TH 01	<i>S. lycopersicum</i>	Tomato	1.00 b	1.00 b	0.00 b		0.00 b / I
Rutgers	<i>S. lycopersicum</i>	Tomato	4.56 a	5.00 a	9857.79 a		17.73 a / S
Average	-	-	1.20	1.22	577.79		1.01
CV%	-	-	9.88	0.22	51.64		27.44
CVg/CV	-	-	7.07	3.54	5.08		3.19
<i>M. incognita</i> race 1							
CNPH 0029	<i>C. annuum</i>	Cayenne	3.50 b	3.50 b	21781.24 a		12.43 b / S
CNPH 4547	<i>C. annuum</i>	Jalapeño	2.67 c	2.67 c	2027.35 d		2.58 d / S
CNPH 30112	<i>C. annuum</i>	Jalapeño	4.50 a	4.50 a	1267.59 d		5.76 c / S
CNPH 30118	<i>C. annuum</i>	Jalapeño	1.00 d	1.00 d	40.32 f		0.06 e / R
CNPH 30147	<i>C. annuum</i>	Jalapeño	1.50 d	1.50 d	1556.29 e		3.27 d / S
CNPH 30159	<i>C. annuum</i>	Jalapeño	2.00 c	2.00 c	736.71 e		2.08 d / S
CNPH 30183	<i>C. annuum</i>	Jalapeño	3.50 b	3.67 b	3598.34 c		7.22 c / S
CNPH 30245	<i>C. annuum</i>	Jalapeño	1.67 d	1.83 c	544.83 e		1.23 d / S
CNPH 6127	<i>C. annuum</i>	Paprika	3.50 b	3.50 b	2431.42 d		7.28 c / S
CNPH 6128	<i>C. annuum</i>	Paprika	2.50 c	2.50 c	1736.20 d		4.40 d / S
CNPH 6132	<i>C. annuum</i>	Paprika	1.00 d	1.00 d	1159.37 e		2.68 d / S
CNPH 6142	<i>C. annuum</i>	Paprika	3.50 b	3.50 b	3391.53 c		9.17 b / S
CNPH 6143	<i>C. annuum</i>	Paprika	4.17 a	4.17 a	5309.42 c		10.44 b / S
CNPH 6144	<i>C. annuum</i>	Paprika	1.00 d	1.00 d	12.74 f		0.07 e / R
CNPH 6625	<i>C. annuum</i>	Paprika	1.50 d	1.50 d	426.83 e		1.83 d / S
CNPH 6628	<i>C. annuum</i>	Paprika	1.33 d	1.33 d	237.92 e		1.03 d / S
TH 01	<i>S. lycopersicum</i>	Tomato	1.00 d	1.00 d	7.68 f		0.04 e / R
Rutgers	<i>S. lycopersicum</i>	Tomato	4.83 a	5.00 a	12827.97 b		27.28 a / S
Average	-	-	2.48	2.51	3282.99		5.49
CV%	-	-	25.12	25.66	37.64		29.76
CVg/CV	-	-	2.07	2.04	2.31		1.84

Table 3 continuation

Genotypes	Species	Type	IG	IMO	Eggs/g	FR/reaction
					<i>M. enterolobii</i>	
CNPH 0029	<i>C. annuum</i>	Cayenne	4.33 b	4.33 b	17277.54 a	1.72 e / S
CNPH 4547	<i>C. annuum</i>	Jalapeño	5.00 a	5.00 a	2923.39 c	1.20 e / S
CNPH 30112	<i>C. annuum</i>	Jalapeño	5.00 a	5.00 a	2247.74 c	2.22 e / S
CNPH 30118	<i>C. annuum</i>	Jalapeño	4.83 a	4.83 a	3967.14 c	3.83 d / S
CNPH 30147	<i>C. annuum</i>	Jalapeño	5.00 a	5.00 a	11036.56 b	5.61 d / S
CNPH 30159	<i>C. annuum</i>	Jalapeño	4.00 c	4.00 c	26258.02 a	10.25 b / S
CNPH 30183	<i>C. annuum</i>	Jalapeño	4.20 b	4.20 b	20625.70 a	5.54 d / S
CNPH 30245	<i>C. annuum</i>	Jalapeño	5.00 a	5.00 a	9488.91 b	9.08 b / S
CNPH 6127	<i>C. annuum</i>	Paprika	5.00 a	5.00 a	6535.46 b	11.48 b / S
CNPH 6128	<i>C. annuum</i>	Paprika	5.00 a	5.00 a	5809.48 b	4.96 d / S
CNPH 6132	<i>C. annuum</i>	Paprika	5.00 a	5.00 a	1193.42 c	2.72 e / S
CNPH 6142	<i>C. annuum</i>	Paprika	5.00 a	5.00 a	3068.29 c	4.89 d / S
CNPH 6143	<i>C. annuum</i>	Paprika	5.00 a	5.00 a	4668.51 b	7.02 c / S
CNPH 6144	<i>C. annuum</i>	Paprika	3.00 d	3.00 d	805.47 c	2.00 e / S
CNPH 6625	<i>C. annuum</i>	Paprika	4.00 c	4.00 c	4425.00 b	10.21 b / S
CNPH 6628	<i>C. annuum</i>	Paprika	4.00 c	4.00 c	2894.68 c	5.41 d / S
TH 01	<i>S. lycopersicum</i>	Tomato	5.00 a	5.00 a	5426.29 b	16.88 a / S
Rutgers	<i>S. lycopersicum</i>	Tomato	5.00 a	4.83 a	7773.71 b	11.20 b / S
Average	-	-	4.63	4.62	7579.18	6.46
CV%	-	-	3.99	4.49	41.45	16.71
CVg/CV	-	-	3.10	2.72	0.97	1.88

IG (gall index) and IMO (egg mass) according to Taylor & Sasser (1978) where 0) roots without egg mass and/or galls; 1) roots with 1 to 2 egg masses and/or galls; 2) roots with 3 to 10 egg masses and/or galls; 3) roots with 11 to 30 egg masses and/or galls; 4) roots with 31 to 100 egg masses and/or galls; 5) roots with over 100 egg masses and/or galls. Eggs/g= number of eggs per gram of roots. FR/reaction (reproduction factor, final population/initial population) according to Oostenbrink (1966) where I= immune (FR= 0); R= resistant (FR<1) and S= susceptible (FR>1). Averages followed by same letters do not differ from each other, Scott-Knott test ($p<0.05$). CV= coefficients of environmental variation. CVg/CV= genotypic and phenotypic coefficients of variation ratio.

(12.30) > *C. frutescens* (9.26), considering the *C. chinense* accession UENF 1730 (FR= 0.30) resistant to *M. enterolobii*.

All pepper genotypes evaluated in this study were resistant or immune to *M. javanica*. Four *C. frutescens* genotypes evaluated in the first experiment were resistant to *M. incognita*, whereas six *C. chinense* genotypes, in the same experiment, were susceptible. For *M. incognita* race 1, all *C. chinense* and *C. annuum* genotypes evaluated in the second experiment were resistant. In the third experiment, in which only *C. annuum* genotypes were evaluated, most were susceptible to *M. incognita*, but genotypes CNPH 30118 and CNPH 6144 were resistant. In relation to *M. enterolobii*, which is the most aggressive species, and few sources of resistance described in literature, a tendency of higher degree of resistance in *C. chinense* and *C. frutescens* was

observed and, although most of the genotypes evaluated in the present study were susceptible, significant differences were observed regarding the degree of susceptibility. This information on different levels of resistance to root-knot nematodes among and in *Capsicum* species is of extreme importance for breeding programs, yet the main contribution of this study was the identification of resistance to *M. enterolobii* in 'BRS Nandaia', a *C. chinense* genotype. Nevertheless, further studies are necessary to investigate molecular bases of this resistance.

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