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## Resistance sources to root-knot nematodes *Meloidogyne javanica*, *M. incognita* and *M. enterolobii* in sweet potato

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### ABSTRACT

One of the main obstacles for food production in many developing countries, as in Brazil, is the damage caused by root-knot nematodes, mainly those belonging to the genus *Meloidogyne*. This study aimed to assess the resistance levels of 44 sweet potato genotypes to *M. javanica*, *M. incognita* race 1 and *M. enterolobii*. These researches were carried out in 2014, under greenhouse conditions in Brasília-DF, Brazil. A completely randomized design with six replicates of one plant/plot/treatment was used. We determined the gall index (GI) and egg mass index (EMI) in the root system of each plant, the number of eggs and juveniles per gram of root with galls and the nematode reproduction factor. *M. javanica* was less aggressive and reproduced in only 9.09% of the evaluated genotypes; *M. incognita* race 1 was intermediate (47.73%); whereas *M. enterolobii* was more aggressive, with a population increase in 79.55% of the genotypes. The genotypes CNPH 1200, CNPH 1219, CNPH 1292, CNPH 1392, CNPH 60 and 'Coquinho' were the most resistant to the three species and can be used in breeding programs for multiple resistance to root-knot nematodes.

**Keywords:** *Ipomoea batatas*, plant breeding, reproduction factor, genetic resistance.

### RESUMO

**Fontes de resistência aos nematoides-das-galhas *Meloidogyne javanica*, *M. incognita* e *M. enterolobii* em batata-doce**

Um dos principais obstáculos para a produção de alimentos em muitos países em desenvolvimento, como no Brasil, é o dano causado por fitonematoides, principalmente os formadores de galhas, pertencentes ao gênero *Meloidogyne*. O trabalho teve como objetivo avaliar o nível de resistência de 44 genótipos de batata-doce a *M. javanica*, *M. incognita* raça 1 e *M. enterolobii*. O experimento foi realizado em 2014, em casa de vegetação, em Brasília-DF. Utilizou-se o delineamento inteiramente casualizado, com seis repetições, constituindo-se de uma planta por tratamento. Foi determinado o índice de galhas (GI) e de massas de ovos (EMI) no sistema radicular de cada planta, quantificado o número de ovos e juvenis por grama de raiz e parte da raiz tuberosa com galhas e efetuado o cálculo do fator de reprodução dos nematoides. Verificou-se que *M. javanica* foi menos agressivo e se reproduziu em apenas 9,09% dos genótipos avaliados. *M. incognita* raça 1 foi intermediário, com 47,73%; enquanto que *M. enterolobii* foi mais agressivo, com aumento populacional em 79,55% dos genótipos. Os genótipos CNPH 1200, CNPH 1219, CNPH 1292, CNPH 1392, CNPH 60 e 'Coquinho' foram os mais resistentes às três espécies avaliadas, podendo ser utilizados no melhoramento visando à resistência múltipla aos nematoides-das-galhas.

**Palavras-chave:** *Ipomoea batatas*, melhoramento genético, fator de reprodução, resistência genética.

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The sweet potato (*Ipomoea batatas*), although being a rustic plant, hosts nematodes of the genus *Meloidogyne*. These nematodes cause great concern regarding production losses in the tropics, subtropics and warm regions all around the world (Atkinson *et al.*, 2012; Bernard *et al.*, 2017; Karuri *et al.*, 2017).

In Brazil, the most important species in sweet potato cultivations are *M. incognita* and *M. javanica* (Charchar & Ritschel, 2004; Chaves *et al.*, 2013)

and, according to Cervantes-Flores *et al.* (2002a), resistant genotypes to multiple species of *Meloidogyne* have been rarely recorded. However, *M. enterolobii*, synonym of *M. mayaguensis*, is gaining prominence due to its ability to infect plants that are resistant to other species of *Meloidogyne* (Carneiro *et al.*, 2006a, 2006b), among them the sweet potato (EPPO, 2014; Rutter *et al.*, 2019).

The root-knot nematodes can reduce absorbent roots, with reduction on

foliage and growth of the sweet potato plant, besides predisposing to the formation of longitudinal cracks in the roots, affecting not only yield, but also quality, conservation and the visual appearance of the commercial product (Perry & Moens, 2006; Bernard *et al.*, 2017).

Several strategies have been used to control root-knot nematodes in sweet potato, among them the use of chemical nematicides, in countries where there

are registered products. Although nematicides are effective, the cost and high toxicity difficult the viability of use. Therefore, the plant genetic resistance, whenever available, is the most efficient method of controlling nematodes, besides being economically sustainable and environmentally safe (Melo *et al.*, 2011; Piedra-Buena *et al.*, 2011; Gomes, 2014; Gomes *et al.*, 2015; Bernard *et al.*, 2017). Although being the genetic resistance of great importance, the integrated control management, also based on prophylactic actions, and biological control, could be more effective.

The aim of this study was to assess the levels of resistance of 44 sweet potato genotypes to *M. javanica*, *M. incognita* race 1 and *M. enterolobii*, to be used in breeding programs as resistance genes sources to root-knot nematodes.

## MATERIAL AND METHODS

The experiments were conducted between December 17, 2013 and April 14, 2014, in a greenhouse at Embrapa Hortaliças, Brasília-DF, Brazil (15°55'44"S, 48°08'29"W, 999 m altitude), whose climatic classification according Köppen, is tropical savanna with rain concentration in summer and dry in winter.

Forty four sweet potato genotypes, from the Active Germplasm Bank of Embrapa Hortaliças, were evaluated for resistance to *M. javanica*, *M. incognita* race 1, which is the nematode race that most occurs in vegetables cultivations in Brazil, including sweet potato, and *M. enterolobii*. The genotypes were chosen due to its superior characteristics and potential to become new cultivars, and not yet characterized to nematode resistance. For each species of nematode, an independent experiment was installed, using a completely randomized design with six replications. Each experimental plot consisted of one plant grown in a 2-L plastic pot, containing substrate on the proportion 1:1:1:1 of subsurface soil (a clay Oxisol, typically encountered in the Savanna Biome region in Brazil), washed sand,

cow manure and carbonized rice husk mix, autoclaved at 121°C for 60 min. We added to 300 g of this mixture 300 g N-P-K, 4-30-16 formulation, and 3,000 g of calcined dolomitic lime. The seedlings were obtained from healthy vines with four intermodal buds from each genotype, and planted individually.

The identification of the root-knot nematodes, *M. javanica*, *M. incognita* race 1 and *M. enterolobii*, was accomplished by morphological examination of the perineal region of adult females and comparison with taxonomic descriptions and keys of Yang & Eisenback (1983); Rammah & Hirschmann (1988) and Eisenback & Hirschmann-Triantaphyllou (1991). To analyze the phenotype of esterase isozyme we used the technique proposed by Carneiro & Almeida (2001). The *Meloidogyne incognita* race was identified according to the differential host test of Taylor & Sasser (1978).

The treatments consisted of clones CNPH 02, CNPH 05, CNPH 08, CNPH 41, CNPH 46, CNPH 53, CNPH 56, CNPH 59, CNPH 60, CNPH 66, CNPH 69, CNPH 80, CNPH 1192, CNPH 1195, CNPH 1197, CNPH 1200, CNPH 1202, CNPH 1208, CNPH 1216, CNPH 1219, CNPH 1220, CNPH 1221, CNPH 1232, CNPH 1292, CNPH 1298, CNPH 1310, CNPH 1344, CNPH 1357, CNPH 1358, CNPH 1361, CNPH 1365, CNPH 1392, CNPH 1393, CNPH 1394, CNPH 1796, CNPH 1805 and CNPH 1809, besides cultivar Rainha and the commercial cultivars Brazlândia Rosada, Brazlândia Branca, Brazlândia Roxa, Coquinho, Princesa and Beauregard. The sweet potato cultivars Brazlândia Roxa and Brazlândia Branca were used as standards of resistance and susceptibility, respectively for *M. javanica* and *M. incognita* race 1, (Charchar & Ritschel, 2004; Marchese *et al.*, 2010; Massaroto *et al.*, 2010). In addition, the tomato 'Santa Cruz' (*Solanum lycopersicum*) was used as susceptibility standard.

Thirty days after planting the vines, eggs and juveniles of second stages (J2) were extracted from the tomato 'Santa Cruz' roots, inoculated previously with each species to be evaluated, according to methodology of Boneti & Ferraz (1981). After the calibration, the

inoculum was distributed over the soil, around the plants, with a concentration equivalent to 5,000 eggs + J2/plant. Plants were irrigated daily, and about one month after inoculation, side dressing was carried out using 3 g of Osmocote® (19-06-10 N-P-K) per liter of substrate.

Plants were harvested 80 days after inoculation, and determined the gall index (GI) and egg mass index (EMI) in the root system of each plant, according to the grades scale proposed by Taylor & Sasser (1978) (0= roots without gall or egg masses; 1= presence of 1 to 2 galls or egg masses; 2= presence of 3 to 10 galls or egg masses; 3= presence of 11 to 30 galls or egg masses; 4= presence of 31 to 100 galls or egg masses and 5= presence of more than 100 galls or egg masses on the root system). The final population of the nematodes in the root system and in the portions of the tuberous roots with galls, were also quantified, extracting the eggs and nematodes using the method of Boneti & Ferraz (1981). The final population (Fp) was quantified, counting the eggs and J2 under an optic microscope. The results were divided by the fresh weight of the root and the part of the tuberous roots with galls and expressed as eggs + J2 per gram of root (FWRG). The nematode reproduction factor (Rf = Fp/Ip) was calculated by dividing the final and initial populations (inoculated). Genotypes presenting Rf less than 1 were considered resistant, and susceptible those presenting Rf greater or equal to the unit (Oostenbrink, 1966).

The data were transformed to  $\sqrt{x+1}$ , to meet the assumptions of normal distribution and homoscedasticity, being presented the original values.

Data were subjected to a one-way analysis of variance (ANOVA), for each characteristic, and means were grouped using the Scott-Knott clustering test at a significance level of 0.05, using Genes software (Cruz, 2013).

## RESULTS AND DISCUSSION

We observed a predominance of variation of genetic order in relation to the environmental variation for most of

the evaluated characters, for the different species of nematodes, according to values higher than the unit for the rate between the genotypic and experimental coefficients of variation (CVg/CV), indicating favorable situation for the characterization of the resistance levels of the genotypes evaluated in the experiments (Tables 1, 2 and 3).

### *Meloidogyne javanica*

Most genotypes (CNPH 02, CNPH 05, CNPH 08, CNPH 41, CNPH 46, CNPH 53, CNPH 56, CNPH 60, CNPH 66, CNPH 69, CNPH 80, CNPH 1195, CNPH 1197, CNPH 1200, CNPH 1202, CNPH 1208, CNPH 1216, CNPH 1219, CNPH 1220, CNPH 1221, CNPH 1232, CNPH 1292, CNPH 1298, CNPH 1310, CNPH 1344, CNPH 1357, CNPH 1358, CNPH 1361, CNPH 1365, CNPH 1392, CNPH 1393, CNPH 1394, CNPH 1796, CNPH 1805, 'Rainha', 'Princesa', 'Brazlândia Rosada', 'Coquinho', 'Brazlândia Roxa' and 'Brazlândia Branca') were resistant to *M. javanica* (Table 1). 'Beauregard' and the clones CNPH 1192, CNPH 1809 and CNPH 59 were susceptible, being the last the best host among the evaluated genotypes, presenting the highest values for gall index, egg mass index and number of eggs + J2 per gram of root and in the portions of tuberous roots with galls, in addition to the highest reproduction factor (17.26).

Cervantes-Flores *et al.* (2002b) evaluated 26 sweet potato genotypes and also verified that most (88.46%) were resistant to *M. javanica*, while the cultivar Beauregard was susceptible. Gomes (2014) also observed resistance of the sweet potato 'Brazlândia Branca' to this nematode.

Silveira & Maluf (1993) evaluated 36 sweet potato clones regarding the resistance to *M. javanica* and identified 23 resistant materials. These authors also verified that the cultivars Brazlândia Roxa, Brazlândia Rosada and Coquinho were resistant. However, the cultivars Brazlândia Branca and Princesa, found being resistant in this research, in that study were considered susceptible.

Charchar & Ritschel (2004) verified that 85.99% of 357 sweet

**Table 1.** Reaction of sweet potato genotypes to infection by *Meloidogyne javanica*. Brasília, Embrapa, 2019.

Genotype	GI	EMI	Rf	Reaction	FWRG
CNPH 56	0.33 e	0.33 e	0.00 d	R	0.00 e
CNPH 1361	0.00 e	0.00 e	0.00 d	R	0.00 e
CNPH 1394	0.33 e	0.17 e	0.00 d	R	0.00 e
CNPH 08	0.00 e	0.00 e	0.00 d	R	0.00 e
CNPH 1393	0.00 e	0.00 e	0.00 d	R	0.00 e
CNPH 66	0.00 e	0.00 e	0.00 d	R	0.00 e
'Brazlândia Rosada'	0.00 e	0.00 e	0.00 d	R	0.00 e
CNPH 1197	0.00 e	0.00 e	0.00 d	R	0.00 e
CNPH 1392	0.00 e	0.00 e	0.00 d	R	0.00 e
CNPH 1195	0.00 e	0.00 e	0.00 d	R	0.00 e
CNPH 1796	0.33 e	0.33 e	0.00 d	R	0.00 e
CNPH 80	0.50 d	0.00 e	0.00 d	R	0.00 e
CNPH 1219	0.50 d	0.50 e	0.02 d	R	6.46 e
'Coquinho'	0.00 e	0.00 e	0.02 d	R	12.08 e
'Brazlândia Roxa'	0.67 d	0.17 e	0.02 d	R	0.99 e
CNPH 1292	0.00 e	0.00 e	0.02 d	R	6.89 e
CNPH 1358	0.00 e	0.00 e	0.03 d	R	13.48 e
CNPH 1805	1.00 d	1.00 d	0.03 d	R	11.57 e
CNPH 1365	0.00 e	0.00 e	0.03 d	R	5.89 e
CNPH 05	0.17 e	0.17 e	0.03 d	R	7.96 e
CNPH 1220	0.00 e	0.00 e	0.05 d	R	68.73 e
CNPH 1298	0.17 e	0.17 e	0.07 d	R	25.08 e
'Rainha'	0.00 e	0.00 e	0.08 d	R	27.79 e
CNPH 1310	0.00 e	0.00 e	0.08 d	R	20.34 e
CNPH 02	0.00 e	0.00 e	0.10 d	R	28.61 e
CNPH 60	0.50 d	0.50 e	0.10 d	R	54.35 e
CNPH 1357	0.00 e	0.00 e	0.12 d	R	145.07 e
CNPH 1232	0.33 e	0.33 e	0.12 d	R	38.39 e
CNPH 46	1.83 c	2.00 b	0.15 d	R	53.63 e
CNPH 69	0.17 e	0.50 d	0.16 d	R	31.15 e
CNPH 1221	1.33 c	1.17 d	0.17 d	R	25.23 e
CNPH 1216	0.83 d	0.83 d	0.22 d	R	53.45 e
CNPH 1200	2.00 c	2.33 b	0.27 d	R	75.66 e
'Brazlândia Branca'	1.50 c	1.33 c	0.37 d	R	104.34 e
CNPH 1208	1.67 c	1.67 c	0.40 d	R	220.52 d
CNPH 41	1.67 c	1.50 c	0.53 d	R	601.37 c
CNPH 1344	2.00 c	2.00 b	0.58 d	R	469.64 d
CNPH 53	1.00 d	1.00 d	0.63 d	R	262.80 d
CNPH 1202	1.50 c	1.67 c	0.75 d	R	256.66 d
'Princesa'	3.33 b	3.33 a	0.85 d	R	268.32 d
CNPH 1192	2.50 c	2.50 b	1.65 c	S	712.09 c

potato accessions were resistant to *M. javanica*, including ‘Brazlândia Roxa’ and ‘Princesa’. However, different from the present study, the cultivars Brazlândia Branca, Brazlândia Rosada and Coquinho presented susceptibility. These differences in the patterns of resistance can occur due to differences on the geographic origin of the isolates, which can result in isolates with greater or lesser degree of virulence, in addition to factors such as high temperatures during the test which can cause resistance loss of materials. Inoculum level or inoculum pressure can also influence, in addition to other factors such as pot size, date of evaluation, among other factors.

### *Meloidogyne incognita*

Only clones CNPH 1358, CNPH 02, CNPH 1361 and CNPH 1202 did not present galls or egg mass in the root systems, caused by *M. incognita* race 1 (Table 2). Genotypes CNPH 1192, CNPH 1216, CNPH 1220, CNPH 1221, CNPH 1298, CNPH 1344, CNPH 1805, CNPH 1809, CNPH 41, CNPH 53, CNPH 59, ‘Princesa’ and ‘Brazlândia Branca’, were statistically equivalent to tomato ‘Santa Cruz’, presenting the highest average indexes of galls and egg masses. Among them, the most susceptible sweet potato genotypes to this nematode were CNPH 1192, CNPH 1216 and CNPH 59, with the highest values of eggs+ $J_2$ /g on roots.

According to the reproduction factor, 52.27% of the genotypes (CNPH 02, CNPH 05, CNPH 08, CNPH 56, CNPH 60, CNPH 69, CNPH 1197, CNPH 1200, CNPH 1202, CNPH 1219, CNPH 1232, CNPH 1292, CNPH 1310, CNPH 1392, CNPH 1358, CNPH 1361, CNPH 1393, CNPH 1394, ‘Brazlândia Roxa’, CNPH 1796, ‘Rainha’, ‘Coquinho’ and ‘Brazlândia Rosada’) were classified as resistant to *M. incognita* race 1. Clones CNPH 46, CNPH 66 and CNPH 1220, did not differ statistically from the previous ones and were only slightly infected. However, due to the reproduction factors greater than 1, were classified as susceptible. Although being these genotypes not extremely resistant, if they have other superior characteristics, they could be tested to,

**Table 1.** continuation ...

Genotype	GI	EMI	Rf	Reaction	FWRG
‘Beauregard’	3.00 b	3.00 a	2.30 c	S	874.93 c
CNPH 1809	3.00 b	3.00 a	2.78 c	S	324.10 d
CNPH 59	4.00 a	4.00 a	17.26 b	S	5298.9 b
Tomato ‘Santa Cruz’	5.00 a	4.17 a	94.31 a	S	11,211 a
Mean	0.91	0.88	2.76	-	473.72
CV (%)	17.24	17.10	38.07	-	76.70
CVg/CVe	1.68	1.68	2.51	-	2.44

Means followed by same letters in the columns do not differ by Scott-Knott hierarchical clustering algorithm, at a significance level of 0.05 for the means/grouping test. CV= environmental coefficient. CVg/CV= genotypic and environmental coefficients relation. GI= Gall Index; EMI= Egg Mass Index (0= without galls or egg mass; 1= 1-2 galls or egg masses; 2= 3-10 galls or egg masses; 3= 11-30 galls or egg masses; 4= 31-100 galls or egg masses and 5= more than 100 galls or egg masses in the root system) (Taylor & Sasser, 1978); Rf= reproduction factor, calculated by dividing the final and initial populations (inoculated); Reaction: degree of resistance (R= resistant and S= susceptible) considering resistant the genotypes with Rf lower than 1 and, susceptible, those that presented Rf higher or equal to 1 (Oostenbrink, 1966); FWRG= eggs +  $J_2$  per root gram part of tuberous root with galls.

**Table 2.** Reaction of sweet potato genotypes to the infection by *Meloidogyne incognita* race 1. Brasília, Embrapa, 2019.

Genotype	GI	EMI	Rf	Reaction	FWRG
CNPH 1219	0.33 d	0.33 d	0.00 d	R	0.00 e
‘Coquinho’	0.17 d	0.17 d	0.00 d	R	0.00 e
CNPH 1392	0.33 d	0.33 d	0.00 d	R	0.00 e
CNPH 1292	0.17 d	0.17 d	0.00 d	R	0.00 e
CNPH 1358	0.00 d	0.00 d	0.02 d	R	14.12 e
CNPH 69	0.17 d	0.00 d	0.03 d	R	12.89 e
CNPH 56	0.17 d	0.33 d	0.04 d	R	35.31 e
CNPH 02	0.00 d	0.00 d	0.05 d	R	13.41 e
CNPH 1361	0.00 d	0.00 d	0.05 d	R	11.39 e
CNPH 1202	0.00 d	0.00 d	0.05 d	R	46.53 e
CNPH 08	0.17 d	0.17 d	0.08 d	R	20.01 e
CNPH 1796	0.50 d	0.50 d	0.10 d	R	90.46 e
CNPH 1394	0.67 c	0.67 d	0.13 d	R	32.72 e
CNPH 1393	0.50 d	0.50 d	0.14 d	R	32.37 e
‘Brazlândia Roxa’	0.33 d	0.33 d	0.15 d	R	30.85 e
CNPH 1197	1.17 c	1.17 c	0.18 d	R	47.90 e
CNPH 1232	1.00 c	1.00 c	0.37 d	R	89.04 e
CNPH 05	1.00 c	1.00 c	0.44 d	R	160.26 e
CNPH 60	2.00 b	2.00 b	0.45 d	R	231.41 d
‘Rainha’	2.00 b	1.33 c	0.50 d	R	405.31 d
CNPH 1200	0.83 c	0.83 c	0.50 d	R	261.43 d
CNPH 1310	2.83 a	2.83 a	0.73 d	R	591.50 d
‘Brazlândia Rosada’	1.67 b	1.17 c	0.92 d	R	195.23 e
CNPH 1220	3.00 a	3.00 a	1.21 d	S	2248.3 c
CNPH 66	1.33 c	1.33 c	1.43 d	S	436.24 d

for example, compose an integrated management system. The highest means for the Rf of this species were observed in the genotypes CNPH 59, CNPH 1192, CNPH 1221, CNPH 1365, CNPH 1805, CNPH 1809, 'Brazlândia Branca' and 'Princesa', indicating susceptibility to the nematode. The genotype 'Beauregard', with reproduction factor 3.9, was also susceptible to *M. incognita* race 1. Likewise, Cervantes-Flores *et al.* (2002b) verified the susceptibility of this cultivar to this nematode.

Maluf *et al.* (1996) evaluated the resistance of 226 sweet potato clones to *M. javanica* and *M. incognita* races 1, 2, 3 and 4, based on the number of egg masses per root, and observed that the frequencies of resistant genotypes were higher to *M. javanica* and lower to *M. incognita* race 2.

Wanderley & Santos (2004) studied the resistance of 35 sweet potato cultivars to *M. incognita*, based on reproduction factor, and observed that 15 were resistant. Similarly, Chaves *et al.* (2013) evaluated the reaction of 25 sweet potato genotypes to *M. incognita* race 2, based on the reproduction index, and verified that 28% of the genotypes were slightly resistant; 52% moderately resistant; 16% highly resistant and that only one genotype was susceptible.

Massaroto *et al.* (2010) evaluated the reaction of 50 sweet potatoes accessions to the infection by *M. incognita* race 1, through the index of egg mass by radicular system, and verified that 15 were highly resistant. Moderate resistance was observed in the cultivar Brazlândia Rosada, corroborating the result found in this work.

Gomes (2014) evaluated the reaction of 63 sweet potato clones to *M. incognita* races 1 and 3, based on reproduction factor, and verified that 66.66% genotypes were resistant to both races. Cultivars Coquinho, Brazlândia Rosada and Brazlândia Branca were resistant to both races. Cultivar Princesa was classified as susceptible. Only cultivar Brazlândia Branca, considered susceptible, presented a different result from that obtained in the present study.

Marchese *et al.* (2010) evaluated 123 sweet potato genotypes for resistance to *M. incognita* race 1, based on

Table 2. continuation...

Genotype	GI	EMI	Rf	Reaction	FWRG
CNPH 46	2.17 b	2.33 b	2.20 d	S	661.25 d
CNPH 1208	2.00 b	2.00 b	2.28 c	S	1789.7 c
CNPH 1195	2.33 b	2.33 b	2.50 c	S	1637.8 c
CNPH 1357	2.33 b	1.83 b	2.74 c	S	1942.2 c
CNPH 41	3.00 a	3.00 a	2.74 c	S	2436.8 c
CNPH 53	3.50 a	3.33 a	3.10 c	S	1502.2 c
CNPH 80	2.50 b	1.00 c	3.61 c	S	2456.3 c
'Beauregard'	1.83 b	1.83 b	3.90 c	S	982.92 d
CNPH 1216	3.67 a	3.67 a	4.20 c	S	3737.2 b
CNPH 1298	3.67 a	3.67 a	4.25 c	S	1638.2 c
CNPH 1344	3.00 a	3.00 a	4.41 c	S	2359.3 c
'Brazlândia Branca'	3.50 a	3.50 a	5.40 b	S	706.58 d
'Princesa'	3.33 a	3.33 a	6.00 b	S	1876.9 c
CNPH 1192	3.67 a	3.67 a	6.05 b	S	5304.3 b
CNPH 1805	3.33 a	3.17 a	6.43 b	S	2004.0 c
CNPH 1221	2.83 a	2.83 a	6.55 b	S	1053.7 c
CNPH 1365	2.33 b	2.33 b	9.82 b	S	2497.2 c
CNPH 59	3.33 a	3.00 a	10.08 b	S	3478.3 b
CNPH 1809	3.67 a	3.67 a	11.02 b	S	2128.6 c
Tomato 'Santa Cruz'	5.00 a	4.00 a	115.2 a	S	18134.0 a
Mean	1.81	1.7	4.89	-	1407.4
CV (%)	15.26	16.03	36.24	-	60.16
CVg/CVe	1.72	1.61	2.23	-	1.61

Means followed by same letters in the columns do not differ by Scott-Knott hierarchical clustering algorithm, at a significance level of 0.05 for the means/grouping test. CV= environmental coefficient. CVg/CVe= genotypic and environmental coefficients relation. GI= Gall Index and EMI= Egg Mass Index (0= without galls or egg masses; 1= 1-2 galls or egg masses; 2= 3-10 galls or egg masses; 3= 11-30 galls or egg masses; 4= 31-100 galls or egg masses and 5= more than 100 galls or egg masses in the root system) (Taylor & Sasser, 1978); Rf= reproduction factor, calculated by dividing the final and initial populations (inoculated); Reaction: degree of resistance (R= resistant and S= susceptible) considering resistant the genotypes with Rf lower than 1 and, susceptible, those that presented Rf higher or equal to 1 (Oostenbrink, 1966); FWRG= eggs + J<sub>2</sub> per root gram part of tuberous root with galls.

reproduction factor. These authors related 57 resistant genotypes, including cultivar Brazlândia Roxa; 'Brazlândia Branca' was susceptible. However, they classified the cultivar Brazlândia Rosada as susceptible, disagreeing with our results.

Charchar & Ritschel (2004) evaluated 357 accessions for resistance to the four races of *M. incognita*, according the average number of egg mass, and verified that 79, 42, 49 and 40 accessions were infected by races 1, 2, 3 and 4, respectively. Cultivars Brazlândia Roxa and Princesa were highly resistant

to all evaluated races, while 'Brazlândia Branca', 'Brazlândia Rosada' and 'Coquinho' were susceptible to race 1. The responses of cultivars Brazlândia Roxa and Brazlândia Branca were congruent with the results obtained in this work.

Silveira & Maluf (1993) also evaluated the reaction of 36 sweet potato genotypes to the production of egg masses of races 1, 2, 3 and 4 of *M. incognita* and verified that 7, 1, 9 and 2 genotypes were resistant to these races, respectively. None genotype was simultaneously resistant to the

four races, indicating independence of resistance sources. About race 1 of *M. incognita*, these authors observed that cultivars Coquinho, Brazlândia Roxa and Brazlândia Branca were susceptible, while cultivar Princesa was resistant. The susceptibility of cultivar Brazlândia Branca is according to the result found in the present work.

#### *Meloidogyne enterolobii*

Regarding *M. enterolobii* (Table 3), no galls or egg masses were observed in the root systems of clones CNPH 1292 and CNPH 1392. Except genotypes CNPH 46, CNPH 56, CNPH 60, CNPH 1200, CNPH 1219, CNPH 1221, CNPH 1809 and 'Princesa', all showed indexes greater than 3 (more than 30 galls and/or egg masses per root systems) for these characters. The genotypes CNPH 02, CNPH 05, CNPH 08, CNPH 59, CNPH 66, CNPH 69, CNPH 1358, CNPH 1298, CNPH 1192, CNPH 1796, CNPH 1208, CNPH 1216, CNPH 1232, CNPH 1344, CNPH 1361, CNPH 1365, CNPH 1805, 'Rainha', 'Brazlândia Branca' and 'Brazlândia Roxa' presented statistically higher values than the egg mass index obtained on tomato 'Santa Cruz', confirming the high aggressiveness of this pathogen.

Except the genotypes CNPH 46, CNPH 60, CNPH 1200, CNPH 1219, CNPH 1221, CNPH 1292, CNPH 1392, CNPH 1809, and 'Coquinho', that were resistant to *M. enterolobii* multiplication, and the genotypes CNPH 1197, CNPH 1202 and 'Princesa', that did not show significant difference compared to the resistant materials; the others were susceptible.

Clone CNPH 1809, with a reproduction factor of 0.52, was resistant to infection by *M. enterolobii*, although being susceptible to *M. javanica* and *M. incognita* race 1. Cultivars Brazlândia Roxa and Brazlândia Rosada, which showed resistance to *M. javanica* and *M. incognita* race 1, were susceptible to *M. enterolobii*. Cultivar Coquinho, with reproduction factor to *M. enterolobii* of 0.40, was resistant to this species and also to *M. javanica* and *M. incognita* race 1. Cultivars Brazlândia Branca and Princesa were susceptible to *M. enterolobii* and *M. incognita* race 1,

**Table 3.** Reaction of sweet potato genotypes to the infection by *Meloidogyne enterolobii*. Brasília, Embrapa, 2019.

Genotypes	GI	EMI	Rf	Reaction	FWRG
CNPH 1392	0.00 d	0.00 d	0.00 e	R	0.00 e
CNPH 1292	0.00 d	0.00 d	0.03 e	R	73.21 e
CNPH 1219	0.83 c	0.67 c	0.13 e	R	77.62 e
CNPH 46	0.67 c	1.00 c	0.24 e	R	27.26 e
CNPH 60	0.50 c	0.67 c	0.28 e	R	282.74 e
CNPH 1221	0.67 c	1.17 c	0.33 e	R	112.63 e
'Coquinho'	3.17 b	3.17 b	0.40 e	R	1.027.5 d
CNPH 1809	1.33 c	2.33 b	0.52 e	R	144.81 e
CNPH 1200	0.83 c	1.17 c	0.83 e	R	160.35 e
CNPH 1197	3.67 b	3.67 b	1.16 e	S	2672.4 d
CNPH 1202	3.33 b	3.67 b	1.65 e	S	1955.7 d
'Princesa'	2.17 b	2.50 b	2.53 e	S	479.18 e
CNPH 56	2.83 b	2.83 b	3.01 d	S	7830.4 c
'Rainha'	3.83 a	4.00 a	4.04 d	S	1896.2 d
CNPH 80	3.00 b	2.67 b	4.65 d	S	5842.8 c
CNPH 1310	3.83 a	3.50 b	5.17 d	S	3250.2 d
CNPH 1195	2.83 b	3.67 b	5.60 d	S	2765.5 d
CNPH 1394	3.67 a	3.67 b	6.38 d	S	4305.0 c
'Beauregard'	3.00 b	3.33 b	6.53 d	S	6293.6 c
CNPH 02	3.83 a	4.33 a	6.57 d	S	2195.1 d
CNPH 66	4.33 a	4.33 a	6.85 d	S	3612.1 c
CNPH 1358	3.67 a	4.17 a	7.18 d	S	5040.1 c
'Brazlândia Roxa'	4.17 a	4.50 a	9.55 d	S	2809.0 d
CNPH 1393	3.33 b	3.33 b	9.77 d	S	13788.3 c
CNPH 53	3.67 a	3.67 b	9.80 d	S	7135.2 c
CNPH 08	4.17 a	4.33 a	10.50 c	S	3129.8 d
CNPH 1805	3.83 a	4.50 a	11.24 c	S	5840.24 c
CNPH 1298	3.50 b	4.17 a	12.70 c	S	4790.5 c
CNPH 1216	4.67 a	4.67 a	14.05 c	S	5254.4 c
CNPH 59	4.17 a	4.00 a	14.22 c	S	2715.3 d
'Brazlândia Branca'	4.00 a	4.00 a	14.33 c	S	6264.2 c
CNPH 41	3.50 b	3.67 b	15.74 c	S	8140.3 c
CNPH 1208	4.33 a	4.67 a	15.87 c	S	5600.7 c
CNPH 69	4.33 a	4.50 a	15.93 c	S	4449.9 c
CNPH 1796	4.33 a	4.50 a	16.17 c	S	7400.9 c
CNPH 1344	4.17 a	4.33 a	16.68 c	S	12195.1 b
'Brazlândia Rosada'	3.17 b	3.50 b	21.70 c	S	6168.5 c
CNPH 1232	4.83 a	5.00 a	22.57 c	S	8995.6 c
CNPH 1357	4.17 a	3.67 b	23.72 c	S	20875.3 b
CNPH 1192	4.17 a	4.17 a	27.32 b	S	15977.7 b
CNPH 1365	4.50 a	4.83 a	30.73 b	S	8672.4 c

Table 3. continuation...

Genotypes	GI	EMI	Rf	Reaction	FWRG
CNPH 05	4.67 a	4.50 a	34.27 b	S	9531.8 c
CNPH 1361	4.83 a	4.67 a	39.72 b	S	14717.4 b
CNPH 1220	4.00 a	3.33 b	45.87 b	S	40226.2 a
Tomato 'Santa Cruz'	5.00 a	3.67 b	96.07 a	S	12592.8 b
Average	3.28	3.39	13.17	-	6162.6
CV (%)	11.83	12.24	51.03	-	53.94
CVg/CVe	1.63	1.46	0.99	-	1.04

Means followed by same letters in the columns do not differ by Scott-Knott hierarchical clustering algorithm, at a significance level of 0.05 for the means/grouping test. CV= environmental coefficient. CVg/CVe= genotypic and environmental coefficients relation. GI= Gall Index and EMI= Egg Mass Index (0= without galls or egg masses; 1= 1-2 galls or egg masses; 2= 3-10 galls or egg masses; 3= 11-30 galls or egg masses; 4= 31-100 galls or egg masses and 5= more than 100 galls or egg masses in the root system) (Taylor & Sasser, 1978); Rf= reproduction factor, calculated by dividing the final and initial populations (inoculated); Reaction: degree of resistance (R= resistant and S= susceptible) considering resistant the genotypes with Rf lower than 1 and, susceptible, those that presented Rf higher or equal to 1 (Oostenbrink, 1966); FWRG= eggs + J<sub>2</sub> per root gram part of tuberous root with galls.

but showed resistance to *M. javanica*. Cultivar Coquinho, the only one resistant to both species of nematodes, is an early cycle cultivar having good root yield, is known as resistant to root-knot nematodes, but presents irregular root shape, ranging from elongated to rounded, pale yellow and unattractive peel; therefore, not widely cultivated, but it could be an alternative to compose an integrated management system in areas infested with root-knot nematodes, or to be used in crossings.

Melo *et al.* (2011) evaluated the resistance of eight sweet potato genotypes to *M. enterolobii*. The authors verified that cultivars Brazlândia Rosada, Brazlândia Roxa and Brazlândia Branca were susceptible and that only two genotypes were resistant, UFLA0749 and UFLA0753. According to these authors, due to the existence of susceptible genotypes to *M. enterolobii* but resistant to other root-knot nematode species, indicate that the resistance to *M. enterolobii*, apparently, is mediated by genes other than those that confer resistance to other species of *Meloidogyne*.

Gonçalves (2011) studied 142 sweet potato clones to the resistance to *M. enterolobii* and found 30 resistant genotypes. In that study, cultivars Brazlândia Rosada, Brazlândia Roxa and Brazlândia Branca were also

susceptible.

Although several studies found in the literature about sweet potato genotype's reaction to root-knot nematodes, there exist few information related to *M. enterolobii*. In the present study many new accessions were evaluated, which provide more options to breeders; but even for those coincident accessions, different results in some researches were verified. These differences may be due to the concept of resistance that, in some cases, is determined by the egg mass index or by the gall visualization and, in some cases, by the reproduction factor. Moreover, experimental factors as temperature, the time the roots remain in the soil before inoculation, the planting date, the life cycle of the nematode, the population density and the stage of development of the root system can interfere in the nematode multiplication and, as a consequence, in the resistance expression (Lawrence *et al.*, 1986). So, even for genotypes evaluated in earlier works, it is important to study the genotypes to confirm or not the resistance pattern, and to define whether these genotypes are resistant to other species of nematodes. About the parameters and concepts, the best parameter to assess resistance is based on the Reproduction Factor, according Oostenbrink. Regarding the Gall Index and Egg Mass Index, these are variables

used to assist the interpretation of the Rf values.

The fact that the evaluated cultivars, that are widely cultivated, have been susceptible, mainly to *M. incognita* and *M. enterolobii*, and the existence of resistant accessions, reinforce the importance of studies like this, to support sweet potato breeding programs. *M. javanica* was the least aggressive species, infecting and reproducing only 9.09% of the studied genotypes. Race 1 of *M. incognita* reproduced in 47.73% of the genotypes. *M. enterolobii* was the most aggressive species, having as susceptible hosts 79.55% of the evaluated genotypes. Genotypes CNPH 1200, CNPH 1219, CNPH 1292, CNPH 1392, CNPH 60 and 'Coquinho' were resistant to *M. javanica*, *M. incognita* race 1 and *M. enterolobii*, being good sources of resistant genes to the three nematode species.

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