RESEARCH/INVESTIGACIÓN

RESISTANCE OF ARRACACHA GENOTYPES TO *MELOIDOGYNE JAVANICA* AND *MELOIDOGYNE INCOGNITA* UNDER FIELD CONDITIONS

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ABSTRACT

Pinheiro J. B., G. O. da Silva, N. R. Madeira, D. Biscaia, A. G. da Silva, and R. A. de C. Melo. 2020. Resistance of arracacha genotypes to *Meloidogyne javanica* and *Meloidogyne incognita* under field conditions. Nematropica 50:69-76.

The losses caused by *Meloidogyne* spp. (root-knot nematodes) are one of the main problems for the production of arracacha (*Arracacia xanthorrhiza*) in Brazil. *Meloidogyne* spp. are widely disseminated in arracacha production areas. An integrated nematode management approach is required, and an important component of this approach is genetic resistance. Studies on the reaction of arracacha genotypes to *Meloidogyne* spp. are scarce. Therefore, the objective of this study was to evaluate arracacha genotypes for resistance to *Meloidogyne* spp. The genotypes selected for evaluation have the potential to be used by farmers, when available, or by breeding programs. Forty genotypes of arracacha, 39 with yellow-colored flesh, and one with white-colored flesh were evaluated. Arracacha 'Amarela Comum' and a white-fleshed variety 'Branca' were included as susceptible and resistant controls, respectively. The experiments were conducted in a field naturally infested with a mixed population of *Meloidogyne javanica* and *Meloidogyne incognita* race 1 in 2011/2012 and 2013/2014. At harvest, root galling was rated and total and commercial storage root mass (t/ha) measured. The mixed population of *M. incognita* race 1 and *M. javanica* significantly affected the quality of arracacha roots and yield. Of the genotypes currently available to growers, 'Amarela de Senador Amaral' and 'Branca' were more resistant to *Meloidogyne* spp. compared to 'Amarela Comum', 'BRS Rúbia 41', 'BRS Acarijó 56', and 'BRS Catarina 64'. Genotypes CNPH-25, CNPH-26, and CNPH-46 were superior for *Meloidogyne* spp. resistance and storage roots mass, making them the most suitable candidates to become new cultivars, or for use in crosses aiming to develop new cultivars that have high-yield potential, yellow-colored flesh, and resistance to *Meloidogyne* spp.

Key words: Arracacia xanthorrhiza, *Meloidogyne incognita, Meloidogyne javanica*, Peruvian carrot

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RESUMO

Pinheiro J. B., G. O. da Silva, N. R. Madeira, D. Biscaia, A. G. da Silva e R. A. de C. Melo 2020. Resistência de genótipos de mandioquinha-salsa ao *Meloidogyne javanica* and *Meloidogyne incognita* sob condições de campo. Nematropica 50:69.76.

As perdas causadas pelo nematoide-das-galhas (*Meloidogyne* spp.) são um dos principais problemas da cultura da mandioquinha-salsa (*Arracacia xanthorrhiza*) no Brasil. *Meloidogyne* spp. encontram-se amplamente disseminados nas áreas de cultivo de mandioquinha-salsa e um sistema de manejo integrado da doença é necessário, sendo a resistência genética um importante componente. São escassos os estudos de reação de genótipos de mandioquinha-salsa ao *Meloidogyne* spp. Assim, objetivou-se neste trabalho avaliar genótipos de mandioquinha-salsa para a resistência a *Meloidogyne* spp. Quarenta genótipos de mandioquinha-salsa, 39 com polpa amarela e um com polpa branca foram avaliados. A variedade de mandioquinha-salsa 'Amarela Comum' e uma variedade de polpa branca 'Branca' foram incluídas como testemunhas suscetível e resistente, respectivamente. Todos os genótipos foram avaliados em cinco repetições. Os experimentos foram conduzidos em um campo naturalmente infestado com uma mistura populacional de *Meloidogyne javanica* e *Meloidogyne incognita* raça 1 em 2011/2012 e 2013/2014. Na colheita foram avaliadas a formação de galhas e a produtividade de raízes comerciais (t/ha). Verificou-se que a mistura populacional de *Meloidogyne incognita* raça 1 e *M. javanica* afetam significativamente a qualidade e o rendimento de raízes. Dentre os genótipos disponíveis atualmente para os produtores, 'Amarela de Senador Amaral' e 'Branca' foram mais resistentes a *Meloidogyne* spp. que 'Amarela Comum', 'BRS Rúbia 41', 'BRS Acarijó 56' e 'BRS Catarina 64'. Os genótipos CNPH-25, CNPH-26, CNPH-46 foram superiores quanto à resistência a *Meloidogyne* spp. e rendimento de raízes, sendo os mais indicados como candidatos a se tornarem novas cultivares, ou para emprego em cruzamentos visando o desenvolvimento de novos clones que apresentem bom potencial de rendimento de raízes, polpa amarela, e resistência a *Meloidogyne* spp.

Palavras chave: Arracacia xanthorrhiza, mandioquinha-salsa, *Meloidogyne incognita* raça 1, *Meloidogyne javanica*

INTRODUCTION

Arracacha or Peruvian carrot (*Arracacia xanthorrhiza*) is an important Andean root and tuber species (Hermann, 1997). In Brazil, it is suited to production by small-scale farmers due to its long growth cycle (approximately 9-12 months) and the high demand of labor during cormel preparation, planting, and harvest. Due to the use of low-quality propagation material, and without a recommended pre-rooting or pre-sprouting period, it is common to have crop failures and reductions in stand establishment (sometimes more than 30%). Additionally, climatic adversities during the production cycle can negatively affect productivity (Madeira and Carvalho, 2016). Another constraint is the absence of commercial propagation material, which requires specific methods that differ from those commonly used in traditional seedling nurseries. The majority of arracacha production is concentrated in the southeast and southern regions of Brazil. The harvested area in the country is estimated at 8,000 ha, producing 110 Mg with an average yield of 13 t/ha in the states of Minas Gerais (3,800 ha), Paraná (2,923 ha), Santa Catarina (550 ha), Espírito Santo (309 ha), and São Paulo (200 ha) (Madeira and Carvalho, 2016).

Among the diseases that cause significant damages to this crop, plant-parasitic nematodes are one of the main problems. Nine nematode genre have been described parasitizing arracacha (Henz, 2002), with root-knot (*Meloidogyne* spp.) and root-lesion (*Pratylenchus* spp.) nematodes being the most important. The *Meloidogyne* spp. most often observed include *M. incognita* and *M. javanica* (Pinheiro *et al*., 2017). These nematodes can reduce the quantity and quality of storage roots, compromising up to 100% of the production in some cases. Additionally, plant growth is reduced, presenting symptoms of chlorosis that often look like nutrient deficiencies. Another noteworthy observed outcome of nematode parasitism is the large proportion of thin and long-shaped storage roots, known in Portuguese as 'palito' (stick) or 'rabicho' (tail) (Pinheiro *et al*., 2017).

Control methods consist of the integration of disease management practices that aim to exclude nematodes and decrease nematode population densities in the soil. Methods include the selection of uncontaminated fields, a 3-yr period without arracacha cultivation or susceptible crops such as carrot, okra, brassica, pumpkins, and tomatoes, the use of nematode-free propagation material (cormels), limiting the movement of contaminated farm machinery, crop rotations with unfavorable hosts or suppressive cover crops, the use of organic matter, fallow and the elimination of plant debris, along with the application of bionematicides and resistant cultivars (Pinheiro, 2017; Ventura *et al*., 2018).

Since *Meloidogyne* and *Pratylenchus* spp. are widespread in areas where arracacha is grown, the use of resistant cultivars has the potential to be a valuable addition to an integrated nematode management strategy. However, information about sources of resistance to nematodes in commercial arrachacha cultivars are scarce. Some cultivars with white-colored flesh roots are relatively tolerant, but their commercial acceptance is restricted due to their unremarkable odor and taste. According to Pinheiro *et al*. (2013b), the variety 'Amarela de Senador Amaral' (ASA), developed by Embrapa and commercially available since 1998, has excellent commercial acceptance, and tolerance to *Meloidogyne* spp. Due to its early development, this variety can reduce the number of generations of these nematodes.

Thus, the study's main objective was the identification of *Meloidogyne* spp.-resistant arracacha genotypes in a natural-infested field with a mixed population of *M. javanica* and *M. incognita* race 1. Selected genotypes may be of value for production, when available in the market, or by breeding programs.

MATERIALS AND METHODS

Forty arracacha genotypes (39 with yellow-colored flesh) were evaluated at Embrapa Vegetables, Brasília - DF, Brazil, during two crop seasons - 2011/2012 and 2013/2014. Plants were established on May 23, 2011 and July 03, 2013, and harvest occurred on April 25, 2012 and April 22, 2014, respectively. Both trials were established in a field with a natural-infested mixed population of *M. javanica* and *M. incognita* race 1, with initial densities of 748 second-stage juveniles (J2)/150 cm³ of soil in 2013 and 673 J2/150 cm³ of soil in 2014. At the end of the trials, final population densities were 2,640 J2/150 cm³ of soil in 2013 and 1,870 J2/150 cm³ of soil in 2014. The species were identified by the perineal pattern of the females and by electrophoretic isoenzyme patterns (Eisenback and Triantaphyllou, 1991; Carneiro and Almeid, 2001). The race of *M. incognita* was determined by the differential hosts test (Taylor and Sasser, 1978). Arracacha 'Amarela Comum' and a white-fleshed variety 'Branca', were included as susceptible and resistant controls, respectively. Within trials, genotypes were arranged in completely randomized blocks replicated five times. Each plot was composed of five plants per genotype, spaced 0.35 m apart in the row with 0.75 m between rows. Fertilizer was applied in the planting furrow, at a rate of 120 g/lm of the commercial formula NPK 04-30-16, plus 40 g/lm of the commercial formula NPK 20-0-20 divided in two applications, 30 and 75 days after planting. All plots received weekly conventional sprinkler irrigation during periods when rainfall was scarce. Weeds were controlled by manual weeding. Other cultural practices were those recommended for the crop according to Embrapa (2008).

At harvest, galling caused by *Meloidogyne* spp. was scored according to Pinheiro *et al*. (2013b), using two independent evaluators to assess all of the plants in a plot where: 1 = absence of symptoms; 2 = presence of symptoms, but all the storage roots are still marketable; 3 = all the storage roots with symptoms, with a few considered marketable; 4 = intense symptoms, with all the storage roots unsuitable for market; 5 = no storage roots formed, with only thin and long shaped roots ('stick' or 'tail' types); the scores of the two evaluators were averaged. The total and commercial storage root mass (t/ha) were determined. Due to the absence of official grades and standards for this species, commercial roots were the ones that had a length $\geq$ 12 cm, $\geq$ 2 cm of root diameter, and root-knot symptoms with a galling score $\leq$ 2 (Pinheiro *et al*., 2013b), and were also free from injuries, internal breakdown, other decay or wet breakdown, and free from damage caused by secondary cuts, bruises, scars, growth cracks, diseases, wireworms, weevils, or other insects. Data were subjected to a one-way analysis of variance (ANOVA). The environmental coefficient of variation (CV), and the relationship between the genotypic CV (Cvg) and the environmental CV (CVg/CV) were calculated according to Cruz *et al.* (2012) using Genes software (Cruz, 2016). Means were grouped using the Scott-Knott clustering test at a significance level of 0.05.

RESULTS AND DISCUSSION

Low values of environmental CVs indicated high experimental accuracy. The ratio (CVg/CV) reflects the predominance of genetic effects expressed for the evaluated characters. Ratio values equal to or above one indicate a favorable situation for selection (Cruz *et al*., 2012). Thus, the genotypes CNPH-21, CNHP-25, CNPH-26, CNHP-35, CNPH-46, CNPH-51, CNPH-53, 'Amarela de Senador Amaral' ('ASA'), and 'Branca' were the most resistant to the mixed population of *M. javanica* and *M. incognita* race 1 in both trials. The genotypes CNPH-19, CNPH-68, CNPH-71, CNPH-80, and 'Amarela Comum', were the most susceptible to the nematodes in both trials (Tables 1 and 2).

In the Brazilian market, arracacha varieties used to decrease nematode population densities are 'ASA' and 'Branca'. Both of these varieties were more resistant than 'Amarela Comum', 'BRS Rúbia 41', 'BRS Acarijó 56', and 'BRS Catarina 64'. This result corroborates the information that 'ASA' and 'Branca Comum' are resistant to *Meloidogyne* spp. (Charchar *et al*., 2007; Pinheiro *et al*., 2013b). The resistance of 'ASA' to *Meloidogyne* spp. may be attributed to the early maturing nature of the variety resulting in fewer nematode generations compared to a late-maturing variety such as 'Amarela Comum'. In this study, and in a previous study (Charchar *et al*., 2007), 'ASA' and 'Amarela Comum' were harvested at the same time; therefore, it appears that time to maturity is not the only determinant of this genetic resistance.

In the 2011/2012 trial, the percentage difference between total and commercial root mass was 25.7%. Among the resistant genotypes it was -15.6% and for the susceptible genotypes -66.4%. This corresponds to a 50.6% difference, indicating that the effects of nematodes on yield and quality of storage roots were greater for the susceptible genotypes (Table 1). In the 2013/2014 trial, the percentage difference between total and commercial root mass was -11.1%. For the resistant genotypes, it was -7.18% and for the susceptible genotype, it was -9.54%. In this trial, the percentage difference between the two groups was only 2.30%, and the quality of the storage roots was impacted less than yield (Table 2). Correlation values between root-knot nematode symptoms and total root mass were -0.6 and -0.4, respectively, in the 2011/2012 trial, whereas they were both -0.4 in the 2013/2014 trial. These results validate that *Meloidogyne* spp. parasitism impacted yield.

The selection of nematode-resistant genotypes for the development of new cultivars or to be used as parents in breeding programs is an important component of nematode management in arracacha. Charchar *et al.* (2007) evaluated 186 genotypes for resistance to the same mixed population (*M. javanica* and *M. incognita* race 1) and classified 'ASA' and 'Amarela Comum' as moderately resistant and highly resistant, respectively, according to the percentage of infected roots. In this study, commercial storage root mass was also evaluated and ranged from 0.0 to 58.7 t/ha. The white flesh-colored variety 'Branca' was the most productive. Among the yellow flesh-colored genotypes, 'ASA' was the most productive with a root mass of 32.4 t/ha, surpassing 'Amarela Comum' with a root mass of 17.1 t/ha. In the present work, among the nine resistant genotypes, higher values of commercial storage root mass were observed for CNPH-25, with a similar mean of 108.9 t/ha in both trials, followed by CNPH-26 (109.0 t/ha) and CNPH-46 (88.2 t/ha). The varieties 'Amarela Comum', 'ASA' and 'Branca' had commercial storage root masses of 20.1, 62.1, and 73.6 t/ha, respectively.

In Brazil, research on arracacha genetics and breeding is scarce. Selection is heavily focused on traits related to adaptation, maturity length, storage roots shape, and color, using seeds harvested at commercial fields to establish a population. These seeds are, in fact, the result of self-pollination, since only one cultivar is usually grown in an area (Sediyama *et al*., 2000). Nonetheless, the development of the new varieties 'BRS Rúbia 41', 'BRS Acarijó 56', and 'BRS Catarina 64' was possible by using a polycross breeding scheme to allow superior genotypes to mate, resulting in half-sib seeds, producing plants with the potential combination of yellow flesh color, high yield, and resistance. The most resistant genotypes identified in this study have the potential to add variability and desirable characteristics by means of recurrent selection, which is a variation of backcross breeding, where selection for performance is practiced within consecutive segregating progeny

Table 1. Plant growth parameters of arracacha genotypes exposed to a mixed population of *Meloidogyne javanica* and *Meloidogyne incognita* race 1 in a 2011/2012 trial.

Genotypes	Root-knot (galls) symptoms scores[w]	Total storage root mass (ha^{-1})	Commercial storage root mass (ha^{-1})
CNPH-04	4.9 a[x]	52.3	36.4
CNPH-07	3.2 c	71.8	56.4
CNPH-13	4.0 b	90.9	63.0
CNPH-14	3.2 c	78.3	61.5
CNPH-15	3.3 c	122.8	108.5
CNPH-16	2.5 d	82.4	53.3
CNPH-17	4.2 b	90.5	58.7
CNPH-19	4.2 b	43.1	37.5
CNPH-20	2.4 d	61.7	31.2
CNPH-21	1.3 f	46.4	29.4
CNPH-23	2.0 e	78.1	69.3
CNPH-25	1.2 f	164.1	142.6
CNPH-26	1.8 e	143.0	128.0
CNPH-28	2.4 d	95.0	79.3
CNPH-31	3.2 c	72.2	44.9
CNPH-35	1.1 f	59.4	40.1
CNPH-39	3.4 c	52.7	41.4
BRS Rúbia 41	4.8 a	61.1	49.3
CNPH-42	3.0 c	73.7	44.9
CNPH-44	4.9 a	53.1	46.1
CNPH-46	1.2 f	116.1	97.7
CNPH-48	3.2 c	75.5	59.7
CNPH-50	4.7 a	89.3	66.3
CNPH-51	1.5 f	65.5	48.7
CNPH-53	1.8 e	87.5	60.1
CNPH-55	3.0 c	32.4	27.0
BRS Acarijó 56	3.4 c	41.3	23.7
CNPH-59	3.9 b	59.0	44.3
CNPH-63	1.9 e	92.2	71.7
BRS Catarina 64	2.8 d	87.4	68.9
CNPH-65	3.3 c	80.3	55.8
CNPH-66	5.0 a	54.9	41.3
CNPH-67	4.3 b	34.1	27.1
CNPH-68	4.4 b	19.9	0.0
CNPH-70	4.8 a	28.1	23.1
CNPH-71	5.0 a	15.7	0.0
CNPH-80	4.9 a	17.2	0.0
Amarela Comum	5.0 a	15.7	0.0
ASA	2.2 e	95.4	69.8
Branca	1.6 f	112.8	82.4
Means	3.2	70.3	52.2
CV[y]	11.4	-	-
CVg/CV[z]	3.4	-	-

[w]Chart scores developed by Pinheiro *et al.* (2013b), where: 1 = absence of symptoms; 2 = presence of symptoms, but all the storage roots are still marketable; 3 = all the storage roots with symptoms, with a few considered marketable; 4 = intense symptoms, with all the storage roots not suitable for market; 5 = no storage roots formed, with only thin and long-shaped roots (‘stick’ or ‘tail’ types).

[x]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.

[y]CV: environmental coefficient.

[z]CVg/CV: environmental and genotypic coefficients relation.

Table 2. Plant growth parameters of arracacha genotypes exposed to a mixed population of *Meloidogyne javanica* and *Meloidogyne incognita* race 1 in a 2013/2014 trial.

Genotypes	Root-knot (galls) symptoms scores[w]	Total storage root mass (ha^{-1})	Commercial storage root mass (ha^{-1})
CNPH-04	2.4 e[x]	73.1 b	64.0 b
CNPH-07	2.9 d	71.9 b	66.2 b
CNPH-13	3.6 c	62.5 c	53.1 c
CNPH-14	2.4 e	69.8 b	64.9 b
CNPH-15	3.4 c	57.0 c	54.9 c
CNPH-16	2.6 d	53.1 d	43.3 c
CNPH-17	1.9 f	57.3 c	50.2 c
CNPH-19	4.7 a	46.5 d	45.2 c
CNPH-20	4.2 b	49.9 d	41.1 c
CNPH-21	1.4 g	67.4 b	55.0 c
CNPH-23	3.3 c	63.2 c	52.7 c
CNPH-25	1.8 f	83.9 a	75.6 a
CNPH-26	1.5 g	94.5 a	89.9 a
CNPH-28	2.5 e	62.1 c	52.8 c
CNPH-31	3.6 c	45.7 d	42.0 c
CNPH-35	1.0 g	57.1 c	47.5 c
CNPH-39	3.9 b	60.9 c	52.8 c
BRS Rúbia 41	2.1 e	69.8 b	61.3 b
CNPH-42	3.1 c	66.3 c	55.5 c
CNPH-44	3.1 c	47.4 d	45.1 c
CNPH-46	1.3 g	85.5 a	78.5 a
CNPH-48	2.4 e	62.2 c	55.7 c
CNPH-50	3.4 c	58.4 c	47.2 c
CNPH-51	2.1 e	60.6 c	51.9 c
CNPH-53	1.8 f	45.7 d	44.8 c
CNPH-55	3.0 c	65.5 c	61.3 b
BRS Acarijó 56	3.4 c	85.6 a	79.9 a
CNPH-59	1.6 f	54.0 d	46.9 c
CNPH-63	2.7 d	54.6 d	47.0 c
BRS Catarina 64	2.7 d	63.9 c	60.2 b
CNPH-65	3.4 c	62.9 c	49.0 c
CNPH-66	2.8 d	49.9 d	45.7 c
CNPH-67	2.8 d	60.3 c	55.5 c
CNPH-68	4.4 b	48.6 d	48.6 c
CNPH-70	3.0 c	59.8 c	54.1 c
CNPH-71	3.9 b	56.4 c	46.0 c
CNPH-80	4.4 b	49.0 d	39.5 c
Amarela Comum	5.0 a	42.2 d	40.2 c
ASA	2.3 e	60.7 c	54.3 c
Branca	2.3 e	72.0 b	64.8 b
Means	2.8	61.4	54.6
CV[y]	13.7	13.0	14.2
CVg/CV[z]	2.4	1.4	1.4

[w]Chart scores developed by Pinheiro *et al*. (2013b), where: 1 = absence of symptoms; 2 = presence of symptoms, but all the storage roots are still marketable; 3 = all the storage roots with symptoms, with a few considered marketable; 4 = intense symptoms, with all the storage roots not suitable for market; 5 = no storage roots formed, with only thin and long-shaped roots (‘stick’ or ‘tail’ types).

[x]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.

[y]CV: environmental coefficient.

[z]CVg/CV: environmental and genotypic coefficients relation.

generations after the population has undergone selection for the major trait (Resende and Barbosa, 2005).

In conclusion, *Meloidogyne* spp. significantly affected root quality and had a small effect on yield of the arracacha genotypes evaluated in these trials. Among the varieties currently available to growers in Brazil, 'ASA' and 'Branca' are more resistant than 'Amarela Comum', 'BRS Rúbia 41', 'BRS Acarijó 56' and 'BRS Catarina 64'. The genotypes CNPH-25, CNPH-26, and CNPH-46 were resistant to the mixed population of *Meloidogyne* spp. and also had high commercial storage root mass. Therefore, these genotypes are considered the most suitable candidates for becoming new cultivars, or for use in breeding programs.

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