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Reaction of Brazilian genotypes of pulses (pea, chickpea and lentil) to the root-knot nematode *Meloidogyne enterolobii*

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Summary – The root-knot nematode, *Meloidogyne enterolobii*, is an important pathogen of numerous crops, including the so-called pulses. Hence, it is necessary to identify genetic resistance, as it is the most efficient, cost-effective, and environmentally sound way to manage nematodes in the field. The objective of this study was to screen a Brazilian germplasm collection of pulse crops (peas, chickpeas, and lentils) comprising accessions from the Embrapa Germplasm Bank and commercial cultivars against *M. enterolobii* under glasshouse conditions. The experiment was conducted with 23 treatments (genotypes), *i.e.*, 14 pea, six chickpea and one lentil genotype, and two tomato cultivars, 'Rutgers' (susceptible) and 'Nemadoro' (resistant). Each plant (replication) was inoculated with 5000 eggs and second-stage juveniles (J2) of *M. enterolobii* and evaluated 65 days after inoculation, considering the following variables: gall index, egg mass index, number of eggs per g of roots, and reproduction factor. The experiments were conducted at two independent time points (summer and autumn/winter). Results showed that all 23 plant genotypes were susceptible to the nematode, with pea genotype 'Itapuã' being intolerant to infection. Cultivation of pulse crops has been steadily increasing both in Brazil and worldwide. Our research findings make a valuable contribution to the ongoing efforts to identify genetic resistance to nematode pathogens that can significantly affect the productivity of these crops. By identifying and developing resistant genotypes, pulse crop yields can be safeguarded, and sustainable agricultural practices can be supported.

Keywords – *Cicer arietinum*, guava root-knot nematode, host, *Lens culinaris*, *Pisum sativum*, reaction, resistance, vegetables.

Legume crops (*Fabaceae* family) have been cultivated as an important food supply due to their contents of high-quality protein (legume crops are the main source of protein for more than 2 billion people worldwide, especially in poor communities) and minerals, vitamins, folate, dietary fibre, antioxidants and health-promoting compounds (Stagnari *et al*., 2017; Çakir *et al*., 2019; Dhaliwal *et al*., 2020).

The subgroup of plants from the *Fabaceae* family, which is referred to as pulses, includes peas (*Pisum sativum* L.), lentils (*Lens culinaris* Medik.), chickpeas (*Cicer arietinum* L.), dry beans (*Phaseolus vulgaris*), cowpeas (*Vigna unguiculata* (L.) Walp) and broad beans (*Vicia faba* L.) (Dhaliwal *et al*., 2020; Trancoso *et al*., 2021). Those plants are cultivated specifically for their dried seeds, *i.e*., pulses, a name that is derived from the Latin word *puls*, which means a thick soup.

The domestic consumption and production of pulses in Brazil are low. However, their demand, especially for chickpea grains, has grown in recent years owing to their nutritional characteristics and changes/trends in food consumption patterns. This has led to importing these products (Artiaga *et al*., 2015; Avelar *et al*., 2018). Nevertheless, the domestic cultivation of pulses is gaining impor-

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tance as an economical option for planting in the second summer harvest (known as 'safrinha' in Portuguese, which means a short crop carried out following the summer main crop, benefiting from the very end of the rainy season) in the Brazilian Cerrado biome. This takes advantage of the drought tolerance of these species, which develop well despite little rainfall, in succession to the soybean crop (Pinheiro *et al.*, 2021). However, when leguminous crops are cultivated repeatedly in the same soil, primarily following a soybean crop, diseases caused by plant-parasitic nematodes can pose risks to the production of pulse crops.

Among the diseases caused by plant-parasitic nematodes, the root-knot nematodes *Meloidogyne* spp., *e.g.*, *M. incognita* (Kofoid & White, 1919) Chitwood (1949), *M. javanica* (Treub, 1885) Chitwood (1949) and *M. artiellia* Franklin (1961), are major constraints for leguminous and other agronomically important crops, causing significant yield losses depending on plant genotypes and nematode levels in the soil (Nascimento *et al.*, 2016; El-Nagdi & Youssef, 2019; Zwart *et al.*, 2019).

Among other *Meloidogyne* species, the guava root-knot nematode, *M. enterolobii* Yang & Eisenback 1983, has been considered a threat to several crops, including legume crops, owing to its widespread distribution, wide host range, virulence, and ability to parasitise genotypes resistant to other *Meloidogyne* species (Sikandar *et al.*, 2022). *Meloidogyne enterolobii* has been detected in different geographic regions worldwide. In Brazil, it was initially reported in guava orchards in 2001 and has since caused great damage to many hosts (Carneiro & Almeida, 2001; Carneiro *et al.*, 2007). Owing to its high reproduction rate and aggressiveness, this species has overcome sources of resistance to other *Meloidogyne* species (Tigano *et al.*, 2010). To date, no information is available on the reactions of accessions and cultivars of peas, lentils or chickpeas to *M. enterolobii*. Soybean cultivars available in the market are susceptible to *M. enterolobii* (Schwarz & Gorny, 2023), increasing the damaging potential of *M. enterolobii* in the Brazilian Cerrado. *Meloidogyne enterolobii* is even more concerning if one considers that this species is spreading rapidly through Brazilian cultivation areas and has already been found to parasitise soybean crops (Versiani *et al.*, 2023).

Several control methods have been used for proper management of root-knot nematodes in infested areas, such as biocontrol, crop rotation, cultural practices and chemical nematicides (Tanimola *et al.*, 2017; Osei *et al.*, 2019). However, no chemical nematicides registered for lentils and chickpeas are currently available in Brazil (Agrofit, 2022). Furthermore, the incorrect use of chemical nematicides can cause side effects in humans and the environment, and a number of these products have been discontinued and are no longer available. Moreover, alternative environmentally sound control methods, such as using genetic resistance, are preferable. This emphasises the need for genetic resistance within the pulse crop germplasm, as it is the most efficient, cost-effective, and environmentally sound way to manage plant-parasitic nematodes in the field (Mattos *et al.*, 2019).

Despite the economic and nutritional value of pulses, only a few studies have reported their genetic resistance against plant pathogens, especially nematodes (Sharma & Gomes, 1992; Lordello & Lordello, 1993; Sharma & Fonseca, 2000; Ansari *et al.*, 2004; Bittencourt & Silva, 2010; Nascimento *et al.*, 2016; Bernardes Neto *et al.*, 2019). Nevertheless, accessions of pulses have been reported to be resistant to species of root-knot nematodes (Sharma *et al.*, 1994; Kumar *et al.*, 2020), including some of the genotypes studied herein ('BRS Aleppo', 'BRS Cícero', 'BRS Cristalino', 'BRS Toro' and 'BRS Kalifa') (Santos *et al.*, 2021). The objective of this study was to screen a germplasm collection of chickpeas, peas and lentils to search for genetic resistance to the guava root-knot nematode, *M. enterolobii*, under glasshouse conditions.

Materials and methods

Plant genotypes

Twenty-one pulse genotypes were tested for host suitability to *M. enterolobii*. These were 14 pea genotypes ('BRS Catarina', 'BRS Dileta', 'BRS Forró', 'BRS Maria', 'BRS Marina', 'BRS Mikado', 'BRS Sulina', 'Eloá', 'G40', 'Itapuã', 'MK-13', 'Petit Pois', 'Telefone alta (Alderman)' and 'Torta de Flor Roxa'), six chickpea genotypes ('BRS Toro', 'BRS Aleppo', 'CNPH 1604 UPL', 'BRS Cristalino', 'BRS Kalifa' and 'BRS Cícero') and one lentil genotype ('BRS Silvina').

Germplasm was obtained from public and private seed companies (Embrapa, Isla, Feltrin, Topseed, and Sakata). Tomato plants (*Solanum lycopersicum* L.) were also included in this study to demonstrate the inoculum viability, optimum growth conditions and as negative ('Rutgers', susceptible) and positive ('Nemadoro', carrying the resistance gene *Mi*) controls. The tomato genotype 'Nemadoro' is resistant to *M. incognita*, *M. javanica* and

M. arenaria (Pinheiro *et al*., 2020) and was included in the experiments to test the ability of *M. enterolobii* to parasitise this cultivar, serving as a resistance standard.

Nematode inoculation

Meloidogyne enterolobii inoculum was obtained from a pure culture multiplied by the periodic subculturing of tomato plants (*S. lycopersicum* 'Santa Cruz'), previously identified as M2 RM 0.7-0.9 using esterase phenotyping and SCAR PCR; and maintained in a glasshouse (25-30°C). Nematode eggs and second-stage juveniles (J2) (eggs + J2) were extracted from infected roots, according to Bonetti & Ferraz (1981). The roots were washed with tap water, and nematode eggs in the egg masses were extracted using 0.5% sodium hypochlorite. Roots were cut into 2-cm-long pieces, mixed with sodium hypochlorite, shaken for 30 s, washed with tap water, and collected using a 500-mesh screen. The total number of eggs per ml was quantified under a light microscope using a nematode-counting slide (Peter's slides). Seedlings (25 days old) were inoculated with 5000 eggs and J2 3 days after being transplanted by placing 10 ml of the suspension into two holes around the plants.

Experimental site, design and settings

The experiments were carried out in a glasshouse at the Nematology Laboratory, Embrapa Vegetables, Gama, DF, Brazil, in two seasons, December 2021 to February 2022 and April to July 2022. The average temperature in the first experiment was 28.7°C (45.6°C maximum and 10.1°C minimum), while in the second experiment the average temperature was 22.7°C (31.7°C maximum and 14.1°C minimum).

The experiments were completely randomised with 23 treatments (14 pea, six chickpea, one lentil and two tomato genotypes) and six replicates. Each plant grown in 2 l pots filled with sterilised soil, sand and Bioplant® organic compost constituted a replication.

Sample processing and data analysis

The roots were carefully removed from the soil, washed with tap water, dried with a paper towel, and the fresh weight of the roots was determined 65 days after inoculation. Roots were stained with floxin B (6 mg l^{-1}), and the following parameters were determined: fresh weight of roots, gall index (GI), egg mass index (EMI), number of eggs + J2 per g root (eggs + J2 (g root)$^{-1}$) = final population/fresh weight of roots), and the nematode reproduction factor (RF = final population/initial population). Nematode eggs + J2 were extracted from the infected roots and quantified as described above.

Plant genotypes were rated according to their reaction to the nematode as a resistant or poor host (RF $<$ 1) or susceptible or suitable host (RF $>$ 1) (Oostenbrink, 1966). Plant genotypes were also rated based on nematode reproduction index (RI) proposed by Taylor (1967), with ratings in relation to a standard of susceptibility: S = susceptible (RI > 50%), SS = slightly susceptible (RI = 26-50%), MoR = moderately resistant (RI = 11-25%), R = resistant (RI = 1-10%), HR = highly resistant (RI < 1%) and I = immune (RI = 0). CV = coefficient of variation.

Data were $\sqrt{x}+0.5$ transformed for statistical analysis, *i.e*., normality test, analysis of variance and Scott-Knott test ($P < 0.05$). The data were back-transformed to present the actual values.

Results

Plant genotypes reacted differently to *M. enterolobii* as inferred from the parameters of GI and EMI (Table 1), eggs + J2 (g root)$^{-1}$, RF (Table 2) and RI (Table 3). In addition, differences in EMI, RF and RI were found in the genotype reactions between the two experiments.

According to Oostenbrink (1966), RF measures the effects of plant genotype on nematode reproduction, where RF $<$ 1 = poor host (P), RF $>$ 1 = suitable host (S), and RF = 0 (I). In the present study, although the results showed a low RF (6.12) for tomato 'Rutgers' (susceptible control) in Experiment 2, probably due to low temperatures during the experiment, the susceptible control showed high RF (26.8) in Experiment 1, indicating good experimental settings and proper conditions for nematode growth and reproduction.

Overall, all the genotypes evaluated (chickpea, pea and lentil) showed RF $>$ 1, characterising them as suitable hosts for *M. enterolobii* (Table 2). However, it is worth mentioning that the RF of pea genotypes 'BRS Catarina' (RF = 4.19 and 4.40 for Experiments 1 and 2, respectively), 'BRS Forró' (RF = 2.17 and 1.51), 'BRS Maria' (RF = 2.91 and 2.21), 'BRS Mikado' (RF = 3.40 and 3.15), 'Eloá' (RF = 3.90 and 3.79) and 'G40' (RF = 2.76 and 1.79) were statistically different (lower) than that of tomato 'Nemadoro' (positive control for resistance to other species of root-knot nematodes) (RF = 17.39 and 5.99) showing lower susceptibility for these pea genotypes in both experiments.

Table 1. Gall index (GI) and egg mass index (EMI) of *Meloidogyne enterolobii* from two experiments on pulse genotypes (pea, chickpea and lentil) under glasshouse conditions 65 days after nematode inoculation.

Genotype	Plant	GI		EMI	
		Experiment 1	Experiment 2	Experiment 1	Experiment 2
'Catarina'	Pea	4.75	5.00	4.75 aA	5.00 aA
'BRS Dileta'	Pea	3.33	4.00	4.00 bA	3.50 bA
'BRS Forró'	Pea	5.00	5.00	3.50 bA	2.75 cA
'BRS Maria'	Pea	2.75	1.75	2.75 bA	1.75 cB
'BRS Marina'	Pea	4.75	4.25	4.50 aA	3.50 bB
'BRS Mikado'	Pea	3.25	4.25	3.75 bA	4.25 aA
'BRS Sulina'	Pea	4.75	4.50	4.75 aA	4.50 aA
'Eloá'	Pea	3.75	4.00	3.75 bA	3.75 bA
'G40'	Pea	4.00	3.50	4.75 aA	3.25 bB
'Itapuã'	Pea	5.00	5.00	5.00 aA	5.00 aA
'Mk13'	Pea	4.00	5.00	4.25 aA	5.00 aA
'Petit Poís'	Pea	4.00	3.00	4.25 aA	2.50 cB
'Telefone Alta'	Pea	4.25	5.00	4.50 aA	4.50 aA
'Flor Roxa'	Pea	5.00	5.00	5.00 aA	5.00 aA
'BRS Toro'	Chickpea	5.00	4.75	5.00 aA	3.00 bB
'BRS Alepp'o	Chickpea	5.00	5.00	4.50 aA	4.00 aA
'CNPH 1604 UPL'	Chickpea	5.00	5.00	4.00 bA	4.50 aA
'BRS Cristalino'	Chickpea	5.00	5.00	4.75 aA	5.00 aA
'BRS Kalifa'	Chickpea	5.00	5.00	5.00 aA	4.75 aA
'BRS Cícero'	Chickpea	5.00	4.75	5.00 aA	4.25 aA
'BRS Silvina'	Lentil	3.75	4.75	3.50 bA	3.50 bA
'Rutgers'	Tomato	5.00	5.00	5.00 aA	4.25 aA
'Nemadoro'	Tomato	5.00	4.75	5.00 aA	3.50 bB
CV		9.9	18.4	11.3	17.4

The data were $\sqrt{x} + 0.5$ transformed but are presented without transformation. Means (n = 6) followed by different letters, lowercase in the columns and uppercase in the rows, are significantly different, according to the Scott-Knott test ($P < 0.05$). Tomato 'Rutgers' is a standard susceptible; tomato 'Nemadoro' is resistant to other *Meloidogyne* species. GI and EMI: grades 1-5, according to Taylor & Sasser (1978). CV = coefficient of variation.

Additionally, the pea 'Itapuã' showed low RF (1.5 and 1.07) (Table 2) and RI (8.92; 27.59); however, it was intolerant to *M. enterolobii* in both experiments. The low RF was due to poor root and shoot development compared with that of a healthy (non-inoculated) plant.

All chickpea genotypes, as well as the single lentil genotype, were susceptible to *M. enterolobii*. However, different susceptibility levels were observed, mainly in the first experiment. 'BRS Toro' (RF = 9.78), 'CNPH 1604 UPL' (RF = 7.49), 'BRS Kalifa' (RF = 10.42), 'BRS Cícero' (RF = 8.78), and lentil 'BRS Silvina' (RF = 5.53) presented lower RF values than 'BRS Aleppo' (RF = 12.27), 'BRS Cristalino' (RF = 13.51), and tomato 'Rutgers' (susceptible, RF = 26.81), and 'Nemadoro' (resistant to other *Meloidogyne* species, RF = 17.37).

According to the criteria proposed by Taylor (1967), different resistance levels to *M. enterolobii* were observed in the genotypes compared to the susceptible tomato control ('Rutgers'). In Experiment 1, 'BRS Catarina', 'BRS Dileta', 'BRS Maria', 'BRS Marina', 'BRS Mikado' and 'BRS Sulina' were classified as slightly susceptible (SS). 'Eloá', 'G40', 'Petit Pois' and 'Flor Roxa' were moderately resistant (MoR), and 'MK 13' and 'Telefone Alta' were rated as highly resistant (HR). However, in Experiment 2, the pea genotypes 'Eloá' and 'Telefone Alta' were classified as slightly susceptible (SS), whereas 'MK-13' was moderately resistant (MoR). All the other genotypes were classified as susceptible (Table 3).

The GI and EMI are auxiliary parameters that can help estimate plant resistance to nematode infections. Generally, a correlation exists between the indices and RF.

Table 2. Eggs and second-stage juveniles (J2) (g root)$^{-1}$ (eggs + J2 (g root)$^{-1}$) and nematode reproduction factor (RF) of *Meloidogyne enterolobii* on pulse genotypes (peas, chickpeas and lentil) under glasshouse conditions 65 days after nematode inoculation.

Genotype	Plant	Eggs + J2 (g root)$^{-1}$ (pooled mean, both experiments)	RF[1]/Reaction[2]	
			Experiment 1	Experiment 2
'BRS Catarina'	Pea	21 308.33 a	4.19 eA/S	4.40 bA/S
'BRS Dileta'	Pea	5901.09 b	4.17 eA/S	5.14 aA/S
'BRS Forró'	Pea	4660.83 b	2.17 eA/S	1.51 bA/S
'BRS Maria'	Pea	2519.63 b	2.91 eA/S	2.21 bA/S
'BRS Marina'	Pea	7556.76 b	7.76 dA/S	5.87 aA/S
'BRS Mikado'	Pea	1703.41 b	3.40 eA/S	3.15 bA/S
'BRS Sulina'	Pea	18 992.54 a	9.42 dA/S	7.65 aA/S
'Eloá'	Pea	3625.27 b	3.90 eA/S	3.79 bA/S
'G40'	Pea	1229.58 b	2.76 eA/S	1.79 bA/S
'Itapuã'	Pea	33 937.50 a	1.50 eA/S	1.07 bA/S
'Mk13'	Pea	16 114.84 a	6.32 dA/S	6.53 aA/S
'Petit Poís'	Pea	2199.78 b	3.93 eA/S	3.72 bA/S
'Telefone Alta'	Pea	10 762.34 b	10.03 dA/S	4.82 aB/S
'Flor Roxa'	Pea	14 976.27 a	13.31 cA/S	6.38 aB/S
'BRS Toro'	Chickpea	5429.77 b	9.78 dA/S	6.64 aA/S
'BRS Aleppo'	Chickpea	6925.05 b	12.27 cA/S	6.62 aB/S
'CNPH 1604 UPL'	Chickpea	6889.68 b	7.49 dA/S	5.22 aA/S
'BRS Cristalino'	Chickpea	3664.65 b	13.51 cA/S	10.76 aA/S
'BRS Kalifa'	Chickpea	7364.98 b	10.42 dA/S	6.41 aB/S
'BRS Cícero'	Chickpea	8461.51 b	8.78 dA/S	6.20 aA/S
'BRS Silvina'	Lentil	7027.73 b	5.53 eA/S	5.17 aA/S
'Rutgers'	Tomato	2219.04 b	26.81 aA/S	6.12 aB/S
'Nemadoro'	Tomato	1094.69 b	17.37 bA/S	5.99 aB/S
CV		–	35.1	68.6

The data were $\sqrt{x} + 0.5$ transformed but are presented without transformation. Means (n = 6) followed by different letters, lowercase in the columns and uppercase in the rows are significantly different, according to the Scott-Knott test ($P < 0.05$). Tomato 'Rutgers' is a standard susceptible; tomato 'Nemadoro' is resistant to other *Meloidogyne* species. CV = coefficient of variation.
[1] RF (reproduction factor) = final population/5000 eggs of *M. enterolobii*.
[2] Reaction of inoculated plants, RF > 1 = suitable host (S) and RF < 1 = poor host (P) (Oostenbrink, 1966).

In the present study, most GI and EMI were correlated with RF. For example, pea genotypes with low RF (Table 2) also showed low GI and EMI values (Table 1).

Discussion

Steady increase in the cultivation of pulse crops, such as peas, chickpeas and lentils, has been experienced worldwide, which is related to the increasing demand for food supply and alternative sources of nutrients. In Brazil, this increase in production occurs mainly at the second summer harvest ('safrinha') in the Brazilian Cerrado biome, which benefits from the drought tolerance of the pulse crops, in a crop succession scheme following the soybean crop (Pinheiro *et al*., 2021). The soybean cultivars available on the market are susceptible to *M. enterolobii* (Schwarz & Gorny, 2023), increasing the damaging potential of *M. enterolobii* in the Brazilian Cerrado biome, considering that this nematode species is rapidly spreading through Brazilian cultivated areas and has already been found to parasitise soybean crops in Brazil (Verssiani *et al*., 2023).

To date, no chemical nematicides are registered for the pulse crops in Brazil. Thus, the search for genetic resistance to *Meloidogyne* spp. in crops is a goal for breeders and growers to achieve sustainable control of these pathogens in the field. To our knowledge, this is one of the few studies that has tested genotypes (commercial cultivars and accessions) to search for genetic resistance

Table 3. Reproduction index (RI) of *Meloidogyne enterolobii* on pulse genotypes (pea, chickpea and lentil) under glasshouse conditions 65 days after nematode inoculation.

Genotype	Plant	RI%[1]	
		Experiment 1/Rating[2]	Experiment 2/Rating
'BRS Catarina'	Pea	37.27 cB/SS	110.29 bA/S
'BRS Dileta'	Pea	27.62 cB/SS	87.80 bA/S
'BRS Forró'	Pea	52.45 bB/S	177.39 aA/S
'BRS Maria'	Pea	46.87 bB/SS	117.66 bA/S
'BRS Marina'	Pea	41.62 bB/SS	108.66 bA/S
'BRS Mikado'	Pea	30.72 cB/SS	104.89 bA/S
'BRS Sulina'	Pea	29.57 cB/SS	106.70 bA/S
'Eloá'	Pea	11.13 cA/MoR	37.16 dA/SS
'G40'	Pea	15.98 cB/MoR	85.27 bA/S
'Itapuã'	Pea	8.92 cA/R	27.59 dA/SS
'Mk13'	Pea	6.50 cA/MoR	19.88 dA/MoR
'Petit Poís'	Pea	14.53 cB/MoR	65.33 cA/S
'Telefone Alta'	Pea	10.58 cA/SS	30.51 dA/SS
'Flor Roxa'	Pea	14.66 cB/MoR	64.47 cA/S
'BRS Toro'	Chickpea	13.04 cB/MoR	55.37 cA/S
'BRS Aleppo'	Chickpea	36.03 cB/SS	131.21 bA/S
'CNPH 1604 UPL'	Chickpea	24.93 cB/SS	111.88 bA/S
'BRS Cristalino'	Chickpea	16.14 cB/MoR	70.85 cA/S
'BRS Kalifa'	Chickpea	51.37 bB/S	108.78 bA/S
'BRS Cícero'	Chickpea	37.52 cB/SS	83.48 bA/S
'BRS Silvina'	Lentil	20.89 cB/MoR	84.73 bA/S
'Rutgers'	Tomato	100.00 aA/S	100.00 bA/S
'Nemadoro'	Tomato	66.27 bB/S	102.80 bA/S

The data were $\sqrt{x} + 0.5$ transformed but are presented without transformation. Means (n = 6) followed by different letters, lowercase in the columns and uppercase in the rows, are significantly different, according to the Scott-Knott test ($P < 0.05$).
[1]RI%: Reproduction index, according to Taylor (1967), tomato 'Rutgers' is a standard susceptible; tomato 'Nemadoro' is resistant to other *Meloidogyne* species.
[2]Ratings: S = susceptible (RI > 50%), SS = slightly susceptible (RI = 26-50%), MoR = moderately resistant (RI = 11-25%), R = resistant (RI = 1-10%), HR = highly resistant (RI < 1%), and I = immune (RI = 0).

within this germplasm. Similar studies have tested several genotypes, for example, Sharma & Gomes (1992) with lentils and Lordello & Lordello (1993), Bernardes Neto *et al*. (2019) and Santos *et al*. (2021) with chickpeas. Studies reporting the reactions of lentil and chickpea genotypes to root-knot nematode species, especially *M. enterolobii*, are scarce.

A pioneering study by Bernardes Neto *et al*. (2019) revealed the response of chickpea genotypes to *M. enterolobii*, making it the first study to report such findings in Brazil, with results showing that all chickpea genotypes tested were susceptible. In their study, 'BRS Cícero' was rated as the least susceptible among the tested genotypes, which was similar to the results reported herein. Likewise, our results showed that all pulse genotypes tested (pea, chickpea and lentil) were susceptible to *M. enterolobii*, with the pea genotype 'Itapuã' being intolerant to this nematode. These findings are consistent with those of previous studies (Sharma & Gomes, 1992; Lordello & Lordello, 1993; Sharma & Fonseca, 2000; Ansari *et al*., 2004; Bittencourt & Silva, 2010; Bernardes Neto *et al*., 2019). This consistency across studies further reinforces the significance of these findings and underscores the need for a continued search for resistance sources in pulse crops.

The lack of resistance to some *Meloidogyne* spp. observed in these pulse crops has also been reported in other leguminous crops, such as dry beans (*Phaseolus vulgaris* L.), which are susceptible to *M. javanica* and *M. paranaensis* (Baida *et al*., 2011), and lima beans (*Phaseo-*

lus lunatus L.), which are susceptible to *M. incognita* and *M. enterolobii* (Bitencourt & Silva, 2010). Kumar *et al*. (2020) reported 19 of 30 pigeon bean genotypes (*Cajanus cajan* (L.) Millsp.) as highly resistant, two as resistant, and three as moderately resistant to *M. javanica*. The authors also reported that four out of 14 mung bean genotypes (*Vigna radiata* (L.) R. Wilczek) were moderately resistant to *M. javanica*.

Five of the six chickpea genotypes tested in the present study were commercial cultivars, all of which showed susceptibility to *M. enterolobii*. 'IAC-Marrocos', a chickpea genotype, is also rated as susceptible to *M. javanica*, *M. arenaria* race 2 and *M. incognita* races 1-4 (Lordello & Lordello, 1993). Further studies reported by Sharma *et al*. (1994) with 47 chickpea accessions from international germplasm banks showed 11 promising genotypes with tolerance to *M. javanica*; however, later studies confirmed only one genotype as tolerant when cultivated in soil infested with *M. javanica* (7.7 nematodes (g soil)$^{-1}$) and *M. incognita* race 1 (10.5 nematodes (g soil)$^{-1}$).

Similar results were reported by Ansari *et al*. (2004), who found that all four chickpea genotypes were susceptible to *M. javanica*. Kumar *et al*. (2020) reported that 19 of 71 chickpea genotypes were highly resistant, eight were resistant, and 12 were moderately resistant to this nematode species. Santos *et al*. (2021) reported resistance in six chickpea genotypes in a field infested with *M. javanica*, including 'BRS Aleppo', 'BRS Cícero', 'BRS Cristalino', 'BRS Toro', 'BRS Kalifa' and 'Jamu 96'. 'BRS Kalifa' and 'Jamu 96' were the most resistant genotypes (Santos *et al*., 2021). These cultivars were rated as susceptible to *M. enterolobii* in this study; nevertheless, they showed RF values lower than those of both the susceptible (RF = 26.81) and resistant (RF = 17.37) standards. Therefore, these cultivars are not recommended for use in fields infested with *M. enterolobii*.

Although Brazil imports lentils, the cultivation area has expanded. Farmers began planting lentils in irrigated areas during winter. Unfortunately, few studies have reported the responses of available cultivars to *Meloidogyne* spp. Sharma & Gomes (1992) found that 'CNPH-237' is highly susceptible to *M. javanica* under field conditions. Similarly, our study revealed that 'Silvina' was susceptible to *M. enterolobii*. Nevertheless, further research is required to determine the resistance of other cultivars to these nematodes.

All 14 pea genotypes tested in this study were susceptible to *M. enterolobii*. Pea genotypes have also been reported to be susceptible to other *Meloidogyne* spp. For example, Charchar *et al*. (2005) reported six pea genotypes susceptible to *M. incognita* race 1. Sharma & Fonseca (2000) reported similar results in their study. Specifically, they found that the pea 'Triofin' was highly susceptible to *M. javanica*, which was evident from the lower fresh and dry weights of both shoots and roots.

Meloidogyne spp. can severely affect the production of pulse crops, and only a few resistant cultivars have been identified to date. Furthermore, even cultivars previously identified as resistant to some species of root-knot nematodes are not resistant to *M. enterolobii*, which is extremely damaging and aggressive to most host crops. Therefore, there is a critical need to screen for new genotypes from germplasm banks worldwide to identify new sources of resistance that can be used to develop new cultivars. Although we did not identify any resistant genotypes, our results provide valuable information on cultivars unsuitable for planting in fields infested with *M. enterolobii*.

In summary, we found that all pulse genotypes tested (chickpeas, peas and lentils) were susceptible to *M. enterolobii*, with the exception of the pea 'Itapuã', which showed intolerance to this nematode. As the total area cultivated with these crops in Brazil and other regions continues to increase, our results provide important insights into the host suitability of these crops for *Meloidogyne* spp. Furthermore, it highlights the need to continue searching for genetic resistance to promote sustainable management of nematodes and other pathogens.

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