

Arabica coffee progenies performance in field infested with root-knot nematodes in the Cerrado Mineiro region

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ABSTRACT

Root-knot nematodes of the genus *Meloidogyne* spp. are important coffee tree parasites. The main species in this crop are *Meloidogyne paranaensis*, *M. incognita*, and *M. exigua*, with the latter being widely disseminated in the country. The best control strategy is the use of resistant cultivars, as it reduces costs and does not pollute the environment. The objective of this work was to evaluate the resistance to *M. exigua* and agronomic characteristics of 34 *Coffea arabica* progenies, originating from crosses between Catuaí group cultivars and Híbrido de Timor selections. The cultivars MGS Paraíso 2, Catuaí Vermelho IAC 144 and IPR 100 were used as witnesses to compare agronomic and resistance performance, since they are already registered and well-established cultivars. Two field experiments were installed in the Cerrado Mineiro region, one in a nematode free field and the other in a naturally infested one by *M. exigua*. Were evaluated vegetative vigor, productivity, fruit yield, percentage of floating fruits, maturation, percentage of flat beans retained on sieve 16 and above, and nematode population in the roots. With superior productivity and lower nematode populations, progenies 2 (39.72 bags ha⁻¹; 17.8 eggs and juveniles root gram⁻¹), 12 (33.52 bags ha⁻¹; 12.01 eggs and juveniles root gram⁻¹), 17 (29.21 bags ha⁻¹; 15.18 eggs and juveniles root gram⁻¹), 28 (25.57 bags ha⁻¹; 32.01 eggs and juveniles root gram⁻¹), and the cultivar MGS Paraíso 2 (30.69 bags ha⁻¹; 16.58 eggs and juveniles root gram⁻¹) showed superior performance in both experiments.

Key words: Coffee Arabica; *Meloidogyne exigua*; Híbrido de Timor; Breeding.

1 INTRODUCTION

Coffee farming is an important agricultural activity in Brazil. The production estimate for 2025 is 55.2 million processed bags, with Minas Gerais accounting for 25.28 million (CONAB, 2025). Coffee tree performance can be affected in various ways; and among biotic factors, nematode parasitism deserves prominence, especially those of the genus *Meloidogyne*. The most relevant species in this crop are *M. paranaensis*, *M. incognita*, and *M. exigua*. The latter reduces plant productivity and is widely distributed in the country (Babilônia et al., 2024; Pereira et al., 2021; Rezende et al., 2019; Rezende et al., 2013).

Nematode management is challenging, as once they are found in an area, eradication is practically impossible. Transportation occurs passively, through rainwater or irrigation and, primarily, by the transit of machinery and implements that carry contaminated soil from one area to another (Salgado et al., 2021). The use of resistant cultivars is the best form of control, as it does not pollute the environment, is highly efficient, and economically viable for the producer, considering the correct identification of the species present in the area is made (Babilônia et al., 2024; Pereira et al., 2021).

Híbrido de Timor originates from a natural cross between *Coffea arabica* and *C. canephora* and has been

widely used in genetic breeding programs due to its resistance to different diseases (Almeida et al., 2022; Noir et al., 2003; Rezende et al., 2014; Sattler et al., 2022). Catuaí group cultivars are known for desirable agronomic characteristics (Fazuoli et al., 2007), and their cross with Híbrido de Timor selections can give rise to plants that combine resistance and superior agronomic traits.

On a survey conducted in the Cerrado Mineiro, that aimed to identify the distribution of *Meloidogyne* species in coffee crops in that region, Babilônia et al. (2024) found out that *M. exigua* was present in 83.8% of the sampled sites collected. Considering the wide dissemination of *M. exigua* in coffee-growing areas in Brazil, its difficult management, and the fact that only thirteen of the 124 coffee cultivars registered with the Ministry of Agriculture, Livestock, and Food Supply (MAPA) are resistant to this species, it is necessary to study and develop new *M. exigua*-resistant cultivars that also show productive potential.

The objective of this work was to evaluate *M. exigua* resistance and agronomic characteristics of 34 *Coffea arabica* progenies, originating from crosses between Catuaí group cultivars and Híbrido de Timor selections, and the cultivars MGS Paraíso 2, Catuaí Vermelho IAC 144 and IPR 100, used as witnesses. The most promising materials will continue to be studied for possible subsequent registration of cultivars.

2 MATERIAL AND METHODS

Two experiments were installed in the Cerrado Mineiro region, under field conditions. One of the experiments was installed on 02/09/2018 on a private property in the municipality of Carmo do Paranaíba-MG, at an altitude of 1.150 m, using a spacing of 3.7 x 0.6 m and in an area irrigated by a drip system. The property had areas infested with root-knot nematode. The identification was made by collecting fine root samples at different points in the area, on both sides and below the plant canopy. The roots were stored in plastic bags and filled with soil to prevent desiccation. The collection was made in December 2019. The samples were sent to the Nematology Laboratory of Federal University of Lavras for identification. The samples were identified as *M. exigua*, esterase enzyme E2 phenotype. Species identification was performed using the isoenzyme electrophoresis technique (Carneiro & Almeida, 2001). The climate in the region is of the Aw type, tropical with dry winter, according to Köppen's classification (Köppen & Geiger, 1928).

The other experiment was installed at the Experimental Field (CEPC) of the Minas Gerais Agricultural Research Company (EPAMIG), in the municipality of Patrocínio-MG. The altitude at the test site is 918 m, with a spacing of 3.5 x 0.7 m, and planting was carried out on 02/07/2018. The area is rainfed and free of root-knot nematodes. The climate in the region is of the Aw type, tropical with dry winter, according to Köppen's classification (Köppen & Geiger, 1928). The experimental design adopted in both experiments was a randomized block design, with three replications and eight plants per plot.

Thirty-four progenies on F_{4,5} generation (Rezende et al., 2013, 2014) and three witnesses' cultivars, MGS Paraíso 2 (susceptible to root-knot nematodes), Catuaí Vermelho IAC 144 (susceptible to root-knot nematodes), and IPR 100 (resistant to *M. paranaensis* and some *M. incognita* races), were used.

Vegetative vigor scores were assigned by two evaluators, before harvest, in July 2020 and July 2021 (Carvalho, Mônico & Fazuoli, 1979). Harvest was carried out manually, and the plot production was measured in liters. Samples of 3 L of freshly harvested coffee were stored in braided polyethylene nets and kept on a concrete patio for drying. Upon reaching 11% moisture content, they were processed and used for the calculation of productivity, in bags of 60 kg of processed coffee per hectare. Yield was calculated by dividing the weight of the processed sample by the weight of the cherry coffee sample.

Fruit maturation was determined by taking a random 0.3 L sample of freshly harvested coffee from each plot, and counting fruits in the "green", "cane green", "cherry", "raisin", and "dry" stages. The values for the "green" and "cane green"

stages were summed, as were those for the "raisin" and "dry" stages, resulting in three maturation groups: "green", "cherry", and "dry".

The percentage of floating fruits was calculated according to Antunes Filho and Carvalho (1954). For granulometric analyses, samples were subjected to a set of circular sieves (17/64 and 16/64 for flat beans) and oblong sieves (11/64 and 10/64 for peaberries), according to MAPA Normative Instruction N° 8 (Brasil, 2003). The weights of the beans retained on each sieve were converted into percentages.

For the quantification of nematode populations, 0.05 kg of fine roots were collected at three points in each plot, on both sides and below the plant canopy. The roots were stored in identified plastic bags filled with soil to prevent desiccation. Collection was performed in the second half of January 2020 and 2021.

In the laboratory, the roots were washed and weighed. Nematodes were extracted according to the technique of Hussey and Barker (1973). The number of eggs and second-stage juveniles per gram of root (NEJGR) for each plot was quantified using an inverted objective optical microscope and a counting slide. The progenies were also grouped concerning Reproduction Reduction, when compared to the susceptible control (Catuaí Vermelho IAC 144), according to Formula 1.

Formula 1. Reduction of root knot nematodes reproduction in the treatments

$$RR = \frac{NEJGRp - NEJGRt}{NEJGRp} \times 100$$

Where,

RR = Reproduction Reduction

NEJGRp = number of eggs and juveniles per gram of root of the susceptible control

NEJGRt = number of eggs and juveniles per gram of root of the treatment

Based on the results, treatments were classified as immune (RR = 100%), highly resistant (RR = 99.9 to 95.1%), resistant (RR = 95 to 90.1%), moderately resistant (RR = 90 to 75.1%), and susceptible (RR = 75 to 0%). For selection purposes in breeding, treatments were ranked according to the Mulamba and Mock Selection Index (1978), which is based on ordering the progenies according to their performance for each characteristic evaluated and the subsequent sum of the positions of each progeny. The best ones are those with the lowest sum values. All characteristics evaluated have the same weight and they were all considered to rank the progenies.

Were evaluated vegetative vigor, productivity, fruit yield, percentage of floating fruits, maturation, percentage of flat beans retained on sieve 16 and above, percentage of flat beans retained on sieve 17 and above and *M. exigua* population in roots in Carmo do Paranaíba experiment. In Patrocínio were evaluated productivity, fruit yield, maturation, floating fruits, percentage of flat beans retained on sieve 16 and above and percentage of flat beans retained on sieve 17 and above. Data were subjected to analysis of variance with a 5% probability level of the F-test. When a significant difference was detected, the means were grouped by the Scott-Knott test at 5% probability. For all characteristics, except NEJGR, the average of data collected in 2020 and 2021 was used.

For NEJGR, analysis of variance was performed separately between the years and transformed using Log(x). The mean test was applied only to 2021 data, as was the grouping concerning Reproduction Reduction, to allow more time for resistance expression by the plants. All statistical analyses were performed using the SISVAR software (Ferreira, 2014).

3 RESULTS

The information regarding the groupings by the mean test is presented in Table 1 for Carmo do Paranaíba experiment and in Table 2 for Patrocínio experiment.

In Carmo do Paranaíba, the treatments were divided into two groups regarding vegetative vigor, with average scores ranging from 8.75 to 7.75 and 7.67 to 6.63. The cultivars MGS Paraíso 2, IPR 100, and 19 progenies are in the group with the highest scores.

Regarding productivity in the Carmo do Paranaíba experiment, four groups were formed. The IPR 100 cultivar presented the highest biennial average, 48.82 bags ha⁻¹, progenies 2, 7, 9, and 12 were statistically similar. These five treatments are also in the group with the highest average vegetative vigor scores. No significant difference for productivity was detected in the Patrocínio experiment (p-value>0.05).

For the fruit yield characteristic, five groups were formed in the Carmo do Paranaíba experiment. The cultivar IPR 100 showed the highest average (52.61%), being the only treatment with an average above 50% and statistically differing from the others (Table 1). Progenies 2, 32, 34, 29, 33, and the cultivars MGS Paraíso 2 and Catuaí Vermelho IAC 144 were in the second group with the highest averages, with values ranging between 49.69% and 47.44% (Table 1). In Patrocínio, three groups were formed, with 25 treatments in the one with the highest averages, which ranged between 46.66% and 41.79% (Table 2). The two cultivars used as witnesses are in this group. No treatment had an average above 50%.

Table 1: Description of treatments, mean vegetative vigor, productivity, processing yield, maturation, floating fruits, flat beans retained on sieve 16 and above, beans retained on sieve 17 and above, and *M. exigua* population in roots (NEJGR = number of eggs and juveniles per gram of root) in 2021 in the experiment in Carmo do Paranaíba.

Treatments	Description of treatments	Vegetative vigor	Productivity (bags ha ⁻¹)	Fruit yield (%)	Maturation (%)			Floating fruits (%)	Flat beans on sieve (%)		NEJGR 2021
					Green	Cherry	Dry		16 and above	17 and above	
1	436-1-4-26-6-BLII	7.21 b	16.74 d	44.31 c	27.77 a	44.66 a	27.57 b	23.50 b	55.88 c	34.66 d	22.35 a
2	518-7-6-71-1-BLIII	8.50 a	39.72 a	49.69 b	29.36 a	35.53 b	35.11 b	6.00 a	81.89 a	69.72 a	17.80 a
3	514-7-14-73-1-BLI	7.38 b	18.85 c	45.12 c	18.45 a	47.85 a	33.70 b	8.83 a	59.87 b	42.10 d	44.69 b
4	504-5-6-117-4-BLI	6.83 b	23.44 c	45.70 c	29.08 a	43.51 a	27.41 b	8.00 a	45.73 d	20.33 f	668.09 b
5	504-5-6-117-7-BLI	6.67 b	12.49 d	40.11 e	31.25 a	41.12 a	27.64 b	18.17 b	44.80 d	28.78 e	1387.84 b
6	504-5-6-117-4-BLII	7.58 b	21.53 c	44.58 c	22.37 a	49.55 a	28.08 b	17.67 b	60.88 b	41.01 d	145.15 b
7	514-7-4-130-1-BLI	8.13 a	37.28 a	46.15 c	53.45 b	32.59 b	13.96 a	10.33 a	53.27 c	23.21 e	19.34 a
8	514-7-4-130-6-BLI	7.83 a	27.65 b	44.51 c	49.01 b	29.50 b	21.49 a	13.83 b	54.12 c	30.43 e	27.38 a
9	514-7-4-130-5-BLIII	8.33 a	33.66 a	45.32 c	44.97 b	37.87 a	17.15 a	10.00 a	54.12 c	36.90 d	11.22 a
10	514-7-4-130-3-BLII	7.67 b	24.66 b	45.17 c	68.98 c	22.35 b	8.67 a	9.67 a	39.39 e	10.84 f	14.00 a

Continue...

Table 1: Continue.

Treatments	Description of treatments	Vegetative vigor	Productivity (bags ha ⁻¹)	Fruit yield (%)	Maturation (%)			Floating fruits (%)	Flat beans on sieve (%)		NEJGR 2021
					Green	Cherry	Dry		16 and above	17 and above	
11	493-1-2-134-5-BLI	8.21 a	30.18 b	46.47 c	37.95 a	38.73 a	23.32 a	6.67 a	47.85 c	15.28 f	11.77 a
12	493-1-2-134-7-BLII	8.75 a	33.52 a	45.79 c	29.70 a	46.71 a	23.59 a	6.17 a	79.03 a	68.37 a	12.01 a
13	493-1-2-134-2-BLII	8.25 a	24.96 b	42.79 d	33.80 a	45.50 a	20.70 a	17.83 b	67.17 b	54.62 b	18.22 a
14	493-1-2-134-7-BLI	8.38 a	24.65 b	45.75 c	31.58 a	41.80 a	26.62 b	13.83 b	69.39 a	55.56 b	15.66 a
15	505-9-2-171-5-BLIII	6.63 b	15.56 d	37.98 e	20.28 a	33.03 b	46.70 b	21.33 b	48.91 c	17.52 f	323.24 b
16	505-9-2-171-5-BLII	7.67 b	11.96 d	38.40 e	29.78 a	38.83 a	31.39 b	17.33 b	56.82 c	31.56 e	1116.65 b
17	514-7-16-208-2-BLII	8.33 a	29.21 b	44.87 c	41.17 b	44.08 a	14.75 a	6.50 a	45.17 d	12.99 f	15.18 a
18	514-7-16-208-5-BLII	8.25 a	27.05 b	44.07 d	28.22 a	48.71 a	23.07 a	5.00 a	50.19 c	15.01 f	14.26 a
19	514-7-16-208-7-BLIII	8.21 a	27.26 b	46.05 c	42.56 b	33.69 b	23.75 a	6.17 a	39.38 e	13.28 f	88.31 b
20	514-7-16-211-7-BLIII	8.00 a	22.82 c	43.88 d	64.00 c	26.98 b	9.02 a	8.33 a	29.68 e	7.40 f	21.07 a
21	514-7-16-211-BLII	8.33 a	18.37 c	43.39 d	36.26 a	43.68 a	20.06 a	5.00 a	46.19 d	15.10 f	184.79 b
22	514-7-16-211-2-BLI	7.75 a	26.54 b	44.54 c	31.59 a	38.37 a	30.04 b	3.83 a	37.78 e	12.19 f	107.30 b
23	514-7-16-359-3-BLI	8.25 a	17.78 c	43.06 d	33.28 a	40.20 a	26.52 b	11.00 a	47.68 c	12.83 f	14.55 a
24	514-7-8-364-4-BLIII	7.21 b	27.17 b	45.16 c	22.86 a	45.66 a	31.48 b	16.17 b	69.10 a	46.26 c	14.34 a
25	514-7-8-364-4-BLII	6.75 b	22.26 c	44.84 c	22.51 a	42.42 a	35.07 b	8.83 a	43.26 d	12.34 f	14.20 a
26	518-2-10-408-4-BLI	7.25 b	20.64 c	46.47 c	26.33 a	43.32 a	30.35 b	6.50 a	56.06 c	30.46 e	23.40 a
27	518-2-10-408-5-BLII	7.33 b	24.83 b	45.23 c	26.58 a	41.05 a	32.37 b	8.00 a	54.64 c	28.49 e	296.66 b
28	518-2-10-408-7-BLI	7.54 b	25.57 b	46.83 c	27.97 a	45.73 a	26.29 b	6.00 a	58.55 b	31.35 e	32.01 a
29	514-5-2-494-3-BLIII	7.92 a	28.76 b	47.75 b	23.23 a	40.04 a	36.74 b	4.83 a	74.42 a	46.70 c	14.85 a
30	518-2-4-593-4-BLI	8.17 a	10.67 d	42.78 d	36.57 a	44.87 a	18.56 a	13.50 b	46.50 d	19.51 f	22.03 a
31	516-8-2-568-8-BLI	7.63 b	21.93 c	42.68 d	43.60 b	37.57 a	18.83 a	15.17 b	63.29 b	37.00 d	10.16 a
32	516-8-2-568-8-BLII	8.17 a	29.94 b	48.41 b	30.19 a	41.16 a	28.65 b	7.67 a	69.76 a	49.67 c	9.62 a
33	516-8-2-568-5-BLII	8.08 a	20.70 c	47.52 b	23.24 a	46.39 a	30.37 b	12.50 b	62.98 b	50.13 c	13.41 a
34	516-8-2-568-6-BLIII	7.58 b	22.29 c	48.23 b	30.37 a	47.57 a	22.06 a	7.83 a	61.54 b	30.09 e	18.21 a
35	MGS Paraíso 2	8.42 a	30.69 b	48.20 b	18.34 a	48.67 a	32.99 b	5.33 a	72.80 a	47.34 c	16.58 a
36	Catuai Vermelho IAC 144	7.29 b	26.81 b	47.44 b	13.17 a	42.86 a	43.97 b	12.33 b	68.92 a	41.55 d	670.39 b
37	IPR 100	8.00 a	42.82 a	52.61 a	52.59 b	40.40 a	7.01 a	8.50 a	75.15 a	51.25 c	5.67 a

BL: Block; NEJGR: number of eggs and juveniles per gram of root. Means followed by the same letter in the column do not differ from each other by the Scott-Knott test at 5% probability.

Table 2: Mean productivity, processing yield, maturation, floating fruits, flat beans retained on sieve 16 and above, and beans retained on sieve 17 and above in the experiment in Patrocínio.

Treatments	Description of treatments	Productivity (bags ha ⁻¹)	Processing yield (%)	Maturation (%)			Floating fruits (%)	Flat beans on sieve (%)	
				Green	Cherry	Dry		16 and above	17 and above
1	436-1-4-26-6-BLII	5.02	37.74 b	59.32 b	27.93 b	12.75 a	29.12 b	34.51 c	16.16 c
2	518-7-6-71-1-BLIII	18.59	44.11 a	55.24 a	35.22 a	9.54 a	7.35 a	51.65 a	34.56 b
3	514-7-14-73-1-BLI	18.05	43.07 a	41.16 a	45.39 a	13.46 a	10.77 a	42.84 b	24.18 b
4	504-5-6-117-4-BLI	10.45	45.86 a	74.18 b	22.95 b	2.87 a	5.00 a	33.26 c	16.14 c
5	504-5-6-117-7-BLI	7.85	35.50 c	57.04 a	33.56 a	9.40 a	14.83 b	37.27 c	20.96 c
6	504-5-6-117-4-BLII	8.92	40.16 b	65.99 b	27.27 b	6.74 a	8.02 a	41.77 b	24.79 b
7	514-7-4-130-1-BLI	16.86	43.20 a	68.17 b	25.06 b	6.77 a	6.25 a	39.36 c	18.06 c
8	514-7-4-130-6-BLI	12.61	37.76 b	55.81 a	28.28 b	15.91 a	15.50 b	33.44 c	17.53 c
9	514-7-4-130-5-BLIII	10.95	40.75 b	50.56 a	38.07 a	11.37 a	12.44 a	43.01 b	29.15 b
10	514-7-4-130-3-BLII	11.67	43.09 a	73.63 b	18.96 b	7.41 a	20.70 b	37.69 c	15.48 c
11	493-1-2-134-5-BLI	12.72	44.00 a	51.09 a	28.95 b	19.96 b	9.54 a	40.97 b	19.48 c
12	493-1-2-134-7-BLII	14.59	45.46 a	50.48 a	38.46 a	11.06 a	8.73 a	62.63 a	45.99 a
13	493-1-2-134-2-BLII	9.41	40.21 b	61.06 b	25.59 b	13.34 a	21.79 b	46.13 b	29.13 b
14	493-1-2-134-7-BLI	12.99	43.72 a	54.57 a	37.15 a	8.28 a	10.53 a	52.27 a	39.20 a
15	505-9-2-171-5-BLIII	8.57	31.04 c	65.13 b	18.09 b	16.77 a	12.48 a	29.38 d	10.99 d
16	505-9-2-171-5-BLII	12.89	37.93 b	66.92 b	25.22 b	7.86 a	23.57 b	44.97 b	24.87 b
17	514-7-16-208-2-BLII	17.23	45.10 a	54.52 a	37.17 a	8.32 a	3.49 a	46.17 b	24.05 b
18	514-7-16-208-5-BLII	11.16	43.39 a	59.47 b	33.06 a	7.47 a	1.17 a	36.99 c	17.67 c
19	514-7-16-208-7-BLIII	20.62	43.44 a	61.88 b	29.04 b	9.09 a	5.68 a	29.22 d	9.02 d
20	514-7-16-211-7-BLIII	12.67	37.12 b	80.47 b	14.41 b	5.12 a	14.89 b	26.91 d	10.29 d
21	514-7-16-211-BLII	13.13	45.41 a	75.21 b	16.28 b	8.51 a	2.75 a	35.62 c	17.44 c
22	514-7-16-211-2-BLI	10.08	45.08 a	66.00 b	24.12 b	9.88 a	6.36 a	25.48 d	8.67 d
23	514-7-16-359-3-BLI	7.67	40.86 b	70.33 b	21.66 b	8.01 a	10.94 a	37.12 c	14.98 c
24	514-7-8-364-4-BLIII	13.99	42.81 a	29.73 a	33.50 a	36.77 c	15.78 b	49.25 a	28.95 b
25	514-7-8-364-4-BLII	7.37	38.32 b	45.45 a	27.93 b	26.62 b	12.77 a	25.38 d	8.42 d
26	518-2-10-408-4-BLI	16.10	46.66 a	54.78 a	39.58 a	5.64 a	4.00 a	47.07 b	30.58 b
27	518-2-10-408-5-BLII	10.68	41.79 a	41.82 a	42.04 a	16.15 a	4.33 a	36.29 c	18.76 c
28	518-2-10-408-7-BLI	12.92	46.19 a	57.20 a	37.45 a	5.34 a	3.58 a	42.63 b	24.16 b
29	514-5-2-494-3-BLIII	8.90	43.20 a	44.21 a	44.67 a	11.12 a	12.51 a	49.18 a	30.71 b
30	518-2-4-593-4-BLI	4.11	42.46 a	69.92 b	24.21 b	5.88 a	13.29 a	37.89 c	17.08 c
31	516-8-2-568-8-BLI	12.87	43.10 a	49.85 a	38.00 a	12.15 a	9.30 a	45.71 b	28.11 b
32	516-8-2-568-8-BLII	8.79	44.75 a	55.35 a	31.55 a	13.10 a	21.19 b	51.41 a	34.11 b
33	516-8-2-568-5-BLII	10.31	45.52 a	65.12 b	27.83 b	7.05 a	12.50 a	45.06 b	32.40 b
34	516-8-2-568-6-BLIII	4.50	44.64 a	77.61 b	15.52 b	6.87 a	21.50 b	30.89 d	11.01 d
35	MGS Paraíso 2	19.77	45.22 a	37.11 a	48.56 a	14.33 a	7.61 a	53.39 a	32.34 b
36	Catuai Vermelho IAC 144	14.93	46.23 a	52.41 a	37.57 a	10.01 a	4.56 a	50.65 a	32.27 b

BL: Block. Means followed by the same letter in the column do not differ from each other by the Scott-Knott test at 5% probability.

Regarding maturation in Carmo do Paranaíba, three groups were formed for fruits in the green phase. The cultivar Catuaí Vermelho IAC 144 showed the lowest average among treatments (13.17%), and progenies 20 and 10 showed the highest, 64% and 68.98% respectively (Table 1). Concerning fruits in the cherry phase, the averages were divided into two groups. Progenies 6 (49.55%) and 18 (48.71%) showed the highest averages, while progenies 10 (22.35%) and 20 (26.98%) showed the lowest (Table 1). For fruits in the dry phase, two groups were formed. The cultivar IPR 100 had the lowest average (7.01%), followed by progenies 10 (8.67%) and 20 (9.02%). Progeny 15 (46.70%), followed by cultivar Catuaí Vermelho IAC 144 (43.97%), were the treatments with the highest averages for fruits in this condition (Table 1).

In Patrocínio, two groups were formed for fruits in the green stage, with 19 treatments in the group with the lowest averages, which ranged between 29.73% and 57.2% (Table 2). Two groups were also formed for cherry fruits, with values between 31.55% and 48.56% (MGS Paraíso 2) in the group with the highest averages (Table 2). For fruits in the dry stage three groups were formed; progeny 24 was the treatment with the highest percentage (36.76%), differing statistically from the others. In the second group were two treatments (progenies 25 and 11), and the remaining 33 treatments were gathered in the group with the lowest averages (values between 16.77% and 2.87%) (Table 2).

For floating fruits in Carmo do Paranaíba, the averages were divided into two groups. The values ranged between 3.83% (progeny 22) and 11% (progeny 23) in the group with the lowest averages (Table 1). In Patrocínio, two groups were also formed for this characteristic, and 26 treatments were in the group with the lowest averages (1.17% to 13.29%) (Table 2).

In Carmo do Paranaíba, for the characteristic of flat beans retained on sieve 16 and above, five groups were formed, and progenies 2 and 12 showed the highest averages, 81.88% and 79.03% respectively (Table 1). Considering only flat beans retained on sieve 17 and above, the averages were divided into six groups, and progenies 2 (69.72%) and 12 (68.37%) also showed the highest values; however, statistically differing from the others (Table 1).

Regarding sieve 16 and above in Patrocínio, four groups were formed, with eight treatments in the group with the highest averages (49.18% to 62.63%) (Table 2). For flat beans retained on sieve 17 and above, the averages were grouped into four groups. Progenies 12 and 14 obtained the highest averages, statistically differing from the others, however no treatment showed an average greater than 50% (Table 2).

The means were divided into two groups regarding the nematode population (Table 1). The group with the lowest means includes 26 treatments, with values between 5.67 (cultivar IPR 100) and 27.38 (progeny 8) eggs and juveniles gram of root⁻¹. These same 26 treatments were classified as

highly resistant by the Reproduction Reduction, which is presented on Table 3.

Table 3: Reduction of Nematode Reproduction in the Carmo do Paranaíba Experiment.

Treatments	Reduction of Reproduction (%)	Classification
1	96.67	HR
2	97.35	HR
3	93.33	R
4	0.34	S
5	-107.02	S
6	78.35	MR
7	97.12	HR
8	95.92	HR
9	98.33	HR
10	97.91	HR
11	98.24	HR
12	98.21	HR
13	97.28	HR
14	97.66	HR
15	51.78	S
16	-66.57	S
17	97.74	HR
18	97.87	HR
19	86.83	MR
20	96.86	HR
21	72.44	S
22	83.99	MR
23	97.83	HR
24	97.86	HR
25	97.88	HR
26	96.51	HR
27	55.75	S
28	95.23	HR
29	97.78	HR
30	96.71	HR
31	98.48	HR
32	98.56	HR
33	98.00	HR
34	97.28	HR
MGS Paraíso 2*	97.53	HR
Catuaí Vermelho IAC 144*	0.00	S
IPR 100*	99.15	HR

HR: highly resistant, R: resistant, MR: moderately resistant, S: susceptible.

*Cultivars used as witnesses.

Another finding was the reduction in the nematode population in the plant roots between the years 2020 and 2021 (Figure 1).

Regarding the reduction of nematode population between the years 2020 and 2021 (Figure 1), treatments 2, 7, 9, 12, and 37 (IPR 100) are in the group with the lowest NEJGR averages and in the group with the highest productivity (Table 1). Treatments 8, 10, 11, 13, 14, 17, 18, 24, 28, 29, 32, and 35 (MGS Paraíso 2) are in the group with the lowest NEJGR averages and in the second group with the highest productivity (Table 1).

The ranking of treatments according to the Mulamba and Mock Index (1978) for both experiments are shown in Table 4.

It is possible to observe that progenies 2, 12, 17, and 28, as well as the MGS Paraíso 2 cultivar, are among the top ten ranked in both experiments.

4 DISCUSSION

In Carmo do Paranaíba the average vegetative vigor scores ranged from 8.75 to 7.75 and 7.67 to 6.63 (Table 1). The cultivars MGS Paraíso 2, IPR 100, and 19 progenies are in the group with the highest scores. This result indicates the good vegetative performance of plants originating from the crossing of Catuaí group cultivars and selections of HdT, like that of more recent cultivars. Similar results have already been reported by other authors (Bonomo et al. 2004; Carvalho et al., 2008), demonstrating the high productive potential combined

with the vegetative vigor of these coffee trees; in addition to the positive correlation that exists between vigor and grain production.

Regarding productivity in the Carmo do Paranaíba experiment the IPR 100 cultivar and the progenies 2, 7, 9 and 12 presented the highest biennial averages (Table 1). These five treatments are also in the group with the highest average vegetative vigor scores. The potential to present high vegetative vigor and productivity by progenies originated from Timor Hybrid selections have already been reported by Maia et al. (2020) and Santos et al. (2022).

No significant difference for productivity was detected in the Patrocínio experiment (Table 2). A possible explanation for this was that low precipitation associated with high temperatures, especially in the initial phases of plant development, harmed growth and consequently the first productions, since the experiment in question was installed in a rainfed area and the highest average productivity found was 20.62 bags ha⁻¹ (progeny 19).

Regarding fruit yield, the cultivar IPR 100 showed the highest average (52.61%), being statistically higher than the others and the only treatment with an average above 50% (Table 1). Progenies 2, 32, 34, 29, 33, and the cultivars MGS Paraíso 2 and Catuaí Vermelho IAC 144 were in the second group. In Patrocínio 25 treatments were in the group with the highest averages, which included MGS Paraíso 2 and Catuaí Vermelho IAC 144 and ranged between 46.66% and 41.79% (Table 2). These results indicate that the progenies presented a fruit yield similar of those of the cultivars.

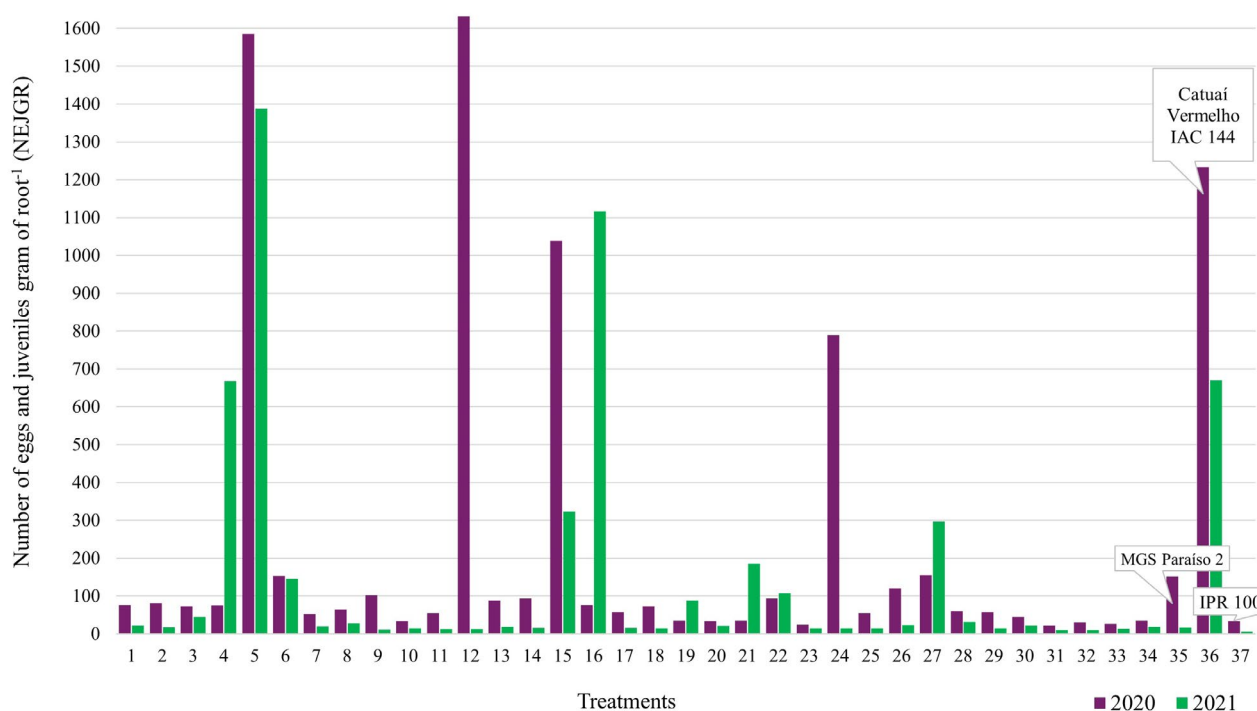


Figure 1: Reduction in root knot nematode population between 2020 and 2021.

Table 4: Ranking of experimental treatments (Mulamba & Mock, 1978).

Carmo do Paranaíba		Patrocínio	
Rank	Treatment	Rank	Treatment
1 °	MGS Paraíso 2*	1 °	26
2 °	12	2 °	MGS Paraíso 2*
3 °	IPR 100*	3 °	17
4 °	18	4 °	Catuaí Vermelho IAC 144*
5 °	17	5 °	28
6 °	2	6 °	3
7 °	32	7 °	12
8 °	11	8 °	14
9 °	28	9 °	2
10 °	33	10 °	19
11 °	29	11 °	27
12 °	13	12 °	31
13 °	9	13 °	18
14 °	19	14 °	29
15 °	6	15 °	22
16 °	14	16 °	24
17 °	21	17 °	32
18 °	26	18 °	30
19 °	24	19 °	23
20 °	3	20 °	9
21 °	34	21 °	5
22 °	7	22 °	6
23 °	23	23 °	33
24 °	31	24 °	11
25 °	Catuaí Vermelho IAC 144*	25 °	21
26 °	30	26 °	7
27 °	27	27 °	4
28 °	22	28 °	10
29 °	25	29 °	20
30 °	4	30 °	16
31 °	1	31 °	15
32 °	20	32 °	13
33 °	5	33 °	1
34 °	10	34 °	8
35 °	8	35 °	25
36 °	16	36 °	34
37 °	15	-	-

*Cultivars used as witnesses.

Fruit yield is the relationship between the weight of processed coffee and the dry coffee fruit (11% of humidity) before it has been processed. It can be influenced by several

factors and reduced due to defects such as peaberries, malformed beans, and empty beans. The higher the fruit yield, the less unprocessed coffee is needed to obtain a 60 kg bag of processed coffee.

Regarding maturation in Carmo do Paranaíba Catuaí Vermelho IAC 144 showed the lowest average among treatments (13,17%), and progenies 20 and 10 showed the highest, 64% and 68.98% respectively (Table 1). Concerning fruits in the cherry phase progenies 6 (49.55%) and 18 (48.71%) showed the highest averages, while progenies 10 (22.35%) and 20 (26.98%) showed the lowest (Table 1). For fruits in the dry phase IPR 100 had the lowest average (7.01%), followed by progenies 10 (8.67%) and 20 (9.02%). Progeny 15 (46.70%), followed by cultivar Catuaí Vermelho IAC 144 (43.97%), were the treatments with the highest averages for fruits in this condition (Table 1).

At the time of harvest, it is desirable to have more than 80% cherry fruits, which corresponds to the physiological maturation phase. Ideally, there should be 5% green fruits, with up to 20% being tolerable, although this compromises coffee quality (Bartholo & Guimarães, 1997). The highest average of cherry fruits found in the biennium was 49.55% (progeny 6) (Table 1), a value below what is considered ideal.

The flowering of the coffee tree typically begins in September. Rainfall or irrigation after a period of water restriction can promote a concentrated bloom; however, this does not always occur, as several flowering events can extend until November. Uneven flowering leads to uneven fruit ripening. Cherry fruit averages below 50% are likely due to the non-uniformity of flowering and subsequent fruit ripening.

Regarding the green fruits, some treatments showed high percentages of fruits in this stage. Progenies 10 (68.98%) and 20 (64%), with the highest averages, differed statistically from the others (Table 1). The cultivar IPR 100 (52.59%), which has a super late ripening cycle (Sera & Sera, 2012), was the fourth treatment with the highest percentage of green fruits. Based on this information, we can hypothesize that progenies 10 and 20 may have a super late ripening cycle; as do progenies 7, 8, 9, 31, 19, and 17, which are in the same group of green fruit averages as the cultivar IPR 100 (Table 1). We can conjecture that the remaining treatments may be of intermediate to late ripening, as they presented the lowest averages of green fruits, like the cultivars Catuaí Vermelho IAC 144 and MGS Paraíso 2.

In Patrocínio 19 treatments in the group with the lowest averages for green fruit, which ranged between 29.73% and 57.2% (Table 2). For cherry fruits values ranged between 31.55% and 48.56% (MGS Paraíso 2) in the group with the highest averages (Table 2). For fruits in the dry stage progeny 24 was the treatment with the highest percentage (36.76%), differing statistically from the others (Table 2). The highest average for cherry fruits was 48.56% (MGS Paraíso 2).

As in Carmo do Paranaíba, no treatment had an average above 50%, possibly due to the non-uniformity in flowering and fruit ripening. Some treatments also presented high percentages of green fruits, such as progeny 20, with the highest average of all (80.47%) (Table 2). It is known that the speed of ripening is highly influenced by environmental conditions, and that the same cultivar located in different places and subjected to different environmental conditions can have its ripening cycle, size of beans, and grain quality affected (Ferreira et al., 2021; Laviola et al., 2007). The cultivars MGS Paraíso 2 and Catuaí Vermelho IAC 144, for example, presented green fruit percentages of 37.11% and 52.42% respectively, still classifying within the group with the lowest averages.

For floating fruits in Carmo do Paranaíba, the values ranged between 3.83% and 11% in the group with the lowest averages (Table 1). In Patrocínio, also in the group with the lowest averages, they ranged between 1.17% and 13.29% (Table 2).

For coffee breeding purposes, values close to 90% of normal fruits are considered satisfactory for selection (Carvalho et al., 2006). In Carmo do Paranaíba, treatments in the group with the lowest averages can be considered satisfactory (Table 1). This group includes 22 progenies and the cultivars MGS Paraíso 2 and IPR 100, which indicates that the studied progenies behave similarly to already registered cultivars. In Patrocínio, 26 treatments were in the group with the lowest averages, including the cultivars used as witnesses (Table 2).

Upon analyzing the data, it is verified that six progenies are in the groups with the highest averages of floating fruits in both experiments (1, 5, 8, 13, 16, 24). It has already been mentioned that fruit yield can be influenced by factors such as peaberries, malformed beans, and empty beans. A possible explanation for lower fruit yield values can be the higher percentage of floating fruits, which can make these progenies unattractive for cultivar registration.

In Carmo do Paranaíba progenies 2 and 12 presented the higher averages for flat beans retained on sieve 16 and above and on 17 and above (Table 1). Regarding sieve 16 and above in Patrocínio eight treatments in the group with the highest averages (Table 2). For flat beans retained on sieve 17 and above progenies 12 and 14 obtained the highest averages, statistically different from the others, however no treatment showed an average greater than 50% (Table 2).

Grains retained on sieve 16 are classified as medium flat according to Normative Instruction N° 8 (Brazil, 2003). In Carmo do Paranaíba the three witnesses' cultivars are in the group with the highest averages, along with progenies 2, 12, 14, 24, 29, and 32. Even in the second group with higher averages, values were above 50%, which demonstrates the potential of the genotypes studied. Grains retained on sieve 17 and above are considered large flat (Brasil, 2003). In Carmo

do Paranaíba progenies 2, 12, 14, 13, 33, and the cultivar IPR 100 can be classified as such, as more than 50% of the grains are found on this sieve.

Other studies have already reported that genotypes descended from crosses with HdT show high percentages for sieve 16 and above (Maia et al., 2020). Progenies 2, 12, 14, 24, 29, 32 and the witnesses' cultivars presented the highest averages for sieve 16 and above in Carmo do Paranaíba and Patrocínio. The high occurrence of larger grains is desirable, as it influences physical appearance and generates more uniform batches for processing; furthermore, grains of the same size ensure uniform coffee roasting (Borém et al., 2021).

Regarding the reduction of nematode population between the years 2020 and 2021 (Figure 1), treatments 2, 7, 9, 12, and 37 (IPR 100) presented the lowest NEJGR averages and are in the group with the highest productivity. Treatments 8, 10, 11, 13, 14, 17, 18, 24, 28, 29, 32, and 35 (MGS Paraíso 2) presented the lowest NEJGR averages and are in the second group with the highest productivity. All mentioned treatments showed a reduction in nematode population in their roots between one year and the next (Figure 1). This is a positive finding because reducing the population density in the area can lower the pressure of parasitism on plants.

Treatments 19, 22, 27, and 36 (Catuaí Vermelho IAC 144) are in the second group with the highest productivities but presented high NEJGR values. Progenies 19 and 22 were classified as moderately resistant, and treatments 27 and 36 (Catuaí Vermelho IAC 144) as susceptible (Table 3). The fact that these genotypes exhibit good productivities even under parasitic conditions suggests that they are possibly tolerant to nematodes. However, these four treatments had the nematode population increased in the roots between one year and the next. Such behavior indicates that these plants can allow the multiplication of the pathogen and consequently the population increase in the area, which is undesirable since high density can generate parasitic pressure and facilitate the transport of the nematode to other locations.

The resistance of the coffee tree to the species *M. exigua* is due to the action of one or more genes located in a single genomic region called the *Mex-1* locus. *C. arabica* plants do not show resistance to nematodes, except for some wild accessions from Ethiopia (Boisseau et al., 2009; Fatobene et al., 2017). The resistance shown by HdT populations to *M. exigua* originates from the species *C. canephora* and occurred due to the introgression of a fragment containing the *Mex-1* locus into arabica coffee plants (Noir et al., 2003). Progenies derived from crosses with HdT have shown promise regarding resistance to *M. exigua* (Barrantes, et al., 2020; Pereira et al., 2021) and other species of the genus (Sera et al., 2021).

Based on the Mulamba and Mock Index (1987) (Table 4) and the conduction of experiments in two different locations we can conjecture about the interaction of genotypes

9 REFERENCES

with the environment, which is important even under unfavorable conditions, as it allows exploring characteristics strongly influenced by the environment. The management of the experiments was quite distinct, and by observing the data, it becomes clear that the management associated with the environmental conditions in Patrocínio interfered in the vegetative performance and plant production.

Progenies 2, 12, 17, and 28, as well as the cultivar MGS Paraíso 2, are among the top ten classified in both experiments (Table 4). This result indicates the potential adaptation of these genotypes to different environments of the Cerrado region and allows concluding that they are the most promising progenies for selection by the breeding program. It should be noted that the cultivar MGS Paraíso 2 is originated from a cross between Catuaí Amarelo IAC 30 and Híbrido de Timor UFV 445-46 (Botelho et al., 2008; Botelho et al., 2019), like the progenies studied here.

5 CONCLUSIONS

Progenies 2, 12, 17, 28 exhibited superior agronomic performance in both environments. In addition to desirable agronomic characteristics, these progenies showed promising behavior regarding root-knot nematodes, with a lower pathogen population in their roots. Based on these results, it is possible to conclude that these genotypes have selection potential and can be used in coffee genetic breeding programs, to obtain plants with superior characteristics that can be cultivated in infested areas with *Meloidogyne exigua*.

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7 AUTHOR CONTRIBUTIONS

Conceptual Idea: Carvalho, G. R.; Ferreira, A. D.; Salgado, S. M. L.; Andrade, V. T. Methodology design: Carvalho, G. R.; Ferreira, A. D.; Salgado, S. M. L.; Andrade, V. T. Data collection: Silvério, L. M. P.; Ferreira, A. D.; Vilela, D. J. M. Data analysis and interpretation: Silvério, L. M. P.; Andrade, V. T., and Writing and editing: Silvério, L. M. P.; Carvalho, G. R.; Ferreira, A. D.].

8 DATA AVAILABILITY STATEMENT

Data available upon request to authors.

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