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3 **Genetic parameters and population reaction of**
4 **coriander to *Meloidogyne incognita* race 1**

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10 **ABSTRACT**
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The genetic parameters provide indispensable information about the genetic behavior of the study population regarding the characters evaluated, providing subsidy to the breeder on the decision of the best selection method in order to obtain gain and maintain adequate variability. In this sense, the present study was carried out to verify the reaction and to estimate genetic parameters of a population composed by two cultivars (Verdão and HTV Dom Luiz) and 49 half-siblings of progenies of coriander parasitized by *Meloidogyne incognita* race 1. The experiment was conducted in a greenhouse in the Department of Agronomy of the Federal Rural University of Pernambuco, in a randomized block design with four replicates and an experimental plot composed by eight plants. The sowing was carried out in a tray of expanded polystyrene of 128 cells with commercial substrate, 1,000 eggs/cell of the pathogen being inoculated on the same day of sowing. After 30 days of inoculation, the number of galls was quantified in the root system, the pathogen's eggs were extracted and, after the quantification of the eggs, the reproduction factor was estimated for each genotype. Data from the three characteristics were compared by Scott-Knott clustering test, they were classified as resistant and susceptible, and genetic parameters were estimated. The genotypes differed from each other at 1% probability level for all the characters under study, being possible to select 12 progenies that were resistant to the pathogen. The heritabilities were high and positive in the values of 75.91 for number of galls in the root system and 96.72 for the number of eggs. Based on the phenotypic and genotypic correlations, it was possible to indicate the selection based on the number of galls in the initial selection cycles, making selection and recombination possible in the same cycle.

12
13 Keywords: *Coriandrum sativum* L., heritability, correlations, root-knot disease.

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15 **1. INTRODUCTION**
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17 Coriander is one of the 12 vegetables with the largest participation in the national market
18 with a tendency to increase in the next few years [1], being extremely cultivated in the
19 Northeast region of Brazil [2]. The planted area of about 73,938 hectares and productivity of
20 15 t/ha, with revenues in the production of seeds and seedlings of \$10.99 and \$243.57
21 millions, respectively [1], reflects the economic importance of the crop in the country due to
22 its market destinations. It ranges from the consumption of its leaves and fruits in nature, to
23 raw material for the food, pharmaceutical, alternative medicine [3] and perfume industry [4].
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25 Several characteristics are to be improved in the crop, such as resistance to early tillage [5],
26 resistance to biotic and abiotic factors [6-7-8], as well as the inherent characteristics of color,
27 aroma and leaf texture. Among the diseases that affect the culture there is caused by
28 species of the genus *Meloidogyne*, with emphasis on *M. incognita* race 1 being the most
29 harmful to coriander [9].

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There are studies in the literature evaluating the reaction of cultivars and progenies of coriander to the attack caused by *M. incognita* race 1 in **searching** to identify superior genotypes that can be a source of resistance to be explored in programs of genetic improvement of the culture [10-11- 9]. The evaluation of populations obtained from different cultivars is fundamental, since the increase of genetic variability is a strategy that must be explored in order to obtain gain from selection.

The study of genetic parameters of characters related to the infection caused by *M. incognita* race 1 is fundamental for the genetic improvement of the culture, for the genetic **parameter statistics** allow identifying the nature of the action of the genes involved in the control of the quantitative characters and to evaluate the efficiency of different breeding strategies, obtaining genetic gains and maintaining an adequate genetic basis. Among the genetic parameters, the most important are: additive and non-additive genetic variances, correlations and **heritability** [12]. In this way, the breeder must choose the best characters to be used in the selective processes, taking into account information such as the CVg/CVa and heritability, since, according to [13], heritability is a genetic parameter of extreme importance to the breeder, the estimation of the part of the phenotypic variance that is due to genetic effects and making possible the choice of the selection methods to be applied.

The objective of this work was to evaluate the reaction and to estimate the genetic parameters of two cultivars and 49 progenies of C2 half-sibs of coriander, regarding the parasitism caused by *M. incognita* race 1.

2. MATERIAL AND METHODS

The experiment was conducted under greenhouse conditions, in the Department of Agronomy of the Federal Rural University of Pernambuco (UFRPE), located at 8°54'47"S, 34°54'47"W, 6m high, in the period from November to December 2017. The monthly average temperatures recorded by the weather station of Recife Curado (automatic) varied between 22.3 - 32.2°C, for minimum and maximum **temperatures**, respectively [14]. The experimental design was a randomized complete block design with four replicates, whose plot was composed of eight plants.

The reactions of two coriander cultivars (Verdão and HTV Dom Luiz) and 49 C2 progenies of coriander half-siblings inoculated with 1,000 eggs/cell at sowing were evaluated.

Of the evaluated progenies, 44 were obtained from the Verdão cultivar, by means of the evaluation of 2,000 plants sown on a tray of expanded polystyrene of 128 cells, inoculated with 1,000 eggs/cell of *M. incognita* race 1 at sowing and evaluated (counting of number of galls) at 30 days after inoculation, selecting plants with gall numbers lower than 10, which were transplanted to 2 L pots containing substrate composed of soil and humus **at** a ratio of 3:1. The pots were placed in the open field at a spacing of 30 cm between plants in the row and 1 m between the lines, so that recombination occurred among the selected individuals. At harvest, each plant had its fruits collected individually and stored in properly identified paper bags, corresponding to the half-sib progenies C1. The progenies obtained in the first cycle were again evaluated with inoculation of 1,000 eggs/cell at sowing in a randomized block design with three replicates and the plot composed by 8 plants. The selection was carried out between and within the progenies in the same cycle, whose selection and recombination adopted the same criterion as the first selective cycle.

The other 5 progenies were obtained from the HTV Dom Luiz cultivar by the same procedure as the Verdão cultivar, with the exception of the **inoculum density** (4,000 eggs/cell) and the

83 selection pressure, where the selected plants should have less than 5 galls in the root
 84 system. The highest density of inoculum in the Dom Luiz HTV cultivar was because it
 85 presented greater tolerance to the pathogen when compared to Verdão in previous
 86 experiments.

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 88 Sowing was carried out in 128-cell expanded polystyrene trays containing the commercial
 89 substrate, placing two coriander seeds at a depth of approximately 0.5 cm, and then
 90 covering with the substrate. Subsequently, water irrigation and inoculation of 1,000 eggs/cell
 91 of *M. incognita* race 1 were performed. Irrigation was carried out daily according to the water
 92 requirement, and fertigation was applied three times a week, preventing drainage with
 93 consequent loss of inoculum.

94
 95 After 30 days of sowing/inoculation, evaluation was performed. For this, the root system was
 96 washed in standing water to remove the substrate. Then, the number of galls was quantified
 97 and the eggs were extracted from each individual plant according to methodology proposed
 98 by [15] and modified by [16]. The extracted eggs were stored in properly identified containers
 99 and placed in a cold chamber until the count was performed using a microscope, increased
 100 40X, and Peters' blade.

101
 102 After quantification of the number of eggs, the reproduction factor (RF) for each sample was
 103 estimated by the ratio between the final population of the pathogen (number of eggs
 104 quantified in the sample) and the initial population of the nematode (1,000 eggs/cell). To
 105 classify the reaction of the cultivars and progenies of coriander to the pathogen, the scale of
 106 [17] was used. Genotypes with RF<1 were considered resistant, and those with RF>1 were
 107 considered susceptible.

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 109 The data obtained were transformed by \sqrt{x} to meet the assumptions of the analysis of
 110 variance, and were submitted to this, with subsequent Scott-Knott grouping test at 5%
 111 probability, using the SISVAR statistical software [18]. The genetic parameters were
 112 estimated by the GENES statistical program [19].

113 114 3. RESULTS AND DISCUSSION

115
 116 There were significant differences in the number of galls in the root system, number of eggs
 117 and reproduction factor at 1% probability, among the evaluated genotypes. The coefficients
 118 of variation ranged from 11.65% to 16.86% (Table 1). Values of CV between 10 and 20%
 119 are considered as medium experimental precision [20], which according to [21] are not of
 120 concern.

121
 122 **Table 1.** Summary of the variance analysis of the number of galls in the root system
 123 (NGRS), number of eggs (NE), and the reproduction factor (RF) of two cultivars and 49
 124 progenies of coriander inoculated with *Meloidogyne incognita* race 1.

SV	DF	QM		
		NGRS ⁺	NE ⁺	RF ⁺
Blocks	3	1.31	81.43	0.08
Genotypes	50	1.33 ^{**}	443.63 ^{**}	0.44 ^{**}
Error	150	0.32	14.57	0.02
QV%		16.86	11.65	11.68
Mean		3.36	32.75	1.04

126 ⁺ Data transformed by \sqrt{x}

127 ** Significant at 1% probability.

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129 For the number of galls in the root system, the means were divided into three groups. In the
130 first group, the means varied between 3.75 - 6.75; in the second group of 8.00 - 11.25 and in
131 the third group of 11.75 - 24.00 (Table 2). The means obtained in the three groups are
132 inferior to those obtained by [9] evaluating the cultivars Verdão, Tabocas, Tapacurá,
133 Palmeira and HTV Dom Luiz in the treatment that had as levels of the factors container and
134 substrate, tray and Basaplant®. These results show that it is possible to obtain promising
135 progenies among those evaluated in the present study, based on this characteristic.

136

137 **Table 2.** Scott-Knott grouping test and reaction of two cultivars and 49 coriander progenies
138 to *M. incognita* race 1, for the following variables: number of galls in the root system
139 (NGRS), number of eggs (NE), and reproduction factor (RF).

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Genotypes	NGRS	NE	RF	Reaction*
67	3.75 a	265.25 a	0.27 a	Resistant
DP10	4.00 a	114.75 a	0.12 a	Resistant
58	4.75 a	311.75 a	0.32 a	Resistant
5	5.00 a	418.25 a	0.42 a	Resistant
69	5.50 a	160.75 a	0.16 a	Resistant
18	6.75 a	526.00 a	0.53 a	Resistant
DP11	8.00 b	225.75 a	0.23 a	Resistant
45	8.75 b	1107.50 b	1.11 b	Susceptible
51	9.00 b	857.75 b	0.86 b	Resistant
DP2	9.00 b	732.75 b	0.73 b	Resistant
8	9.50 b	746.00 b	0.75 b	Resistant
Verdão	9.75 b	1328.50 c	1.33 c	Susceptible
29	10.00 b	266.00 a	0.27 a	Resistant
4	10.25 b	2539.25 e	2.54 e	Susceptible
21	10.25 b	629.25 b	0.63 b	Resistant
31	10.25 b	576.00 a	0.58 a	Resistant
1	10.50 b	1159.50 b	1.16 b	Susceptible
40	10.83 b	750.25 b	0.75 b	Resistant
47	11.00 b	1037.50 b	1.04 b	Susceptible
64	11.19 b	487.00 a	0.49 a	Resistant
60	11.25 b	1445.00 c	1.45 c	Susceptible
54	11.25 b	1467.25 c	1.47 c	Susceptible
38	11.75 c	1556.25 c	1.56 c	Susceptible
19	11.75 c	879.75 b	0.88 b	Resistant
16	12.00 c	1902.75 d	1.90 d	Susceptible
15	12.44 c	1601.75 c	1.60 c	Susceptible
14	12.50 c	1564.00 c	1.57 c	Susceptible
49	12.50 c	1817.50 d	1.82 d	Susceptible
DP6	12.75 c	267.25 a	0.27 a	Resistant
HTV Dom Luiz	12.75 c	1711.50 d	1.71 d	Susceptible
33	13.00 c	1705.00 d	1.71 d	Susceptible
57	13.00 c	1542.25 c	1.54 c	Susceptible
3	13.50 c	1328.25 c	1.33 c	Susceptible
23	13.50 c	953.50 b	0.95 b	Resistant
42	13.50 c	1393.25 c	1.40 c	Susceptible
24	13.75 c	1503.00 c	1.50 c	Susceptible
44	13.75 c	1091.00 b	1.09 b	Susceptible
56	14.00 c	2596.25 e	2.60 e	Susceptible

48	14.00 c	2358.50 e	2.36 e	Susceptible
22	14.25 c	676.00 b	0.68 b	Resistant
DP1	14.25 c	1273.25 c	1.28 c	Susceptible
20	14.50 c	820.50 b	0.82 b	Resistant
28	14.75 c	474.50 a	0.48 a	Resistant
46	14.75 c	1394.50 c	1.40 c	Susceptible
32	15.06 c	1348.63 c	1.35 c	Susceptible
12	15.25 c	1838.25 d	1.84 d	Susceptible
34	16.25 c	2337.50 e	2.34 e	Susceptible
53	16.75 c	1783.25 d	1.79 d	Susceptible
50	17.00 c	1945.50 d	1.95 d	Susceptible
52	17.00 c	2169.00 e	2.17 e	Susceptible
30	24.00 c	1876.75 d	1.88 d	Susceptible

141 * Oostenbrink scale (1966), resistant FR<1 and susceptible FR>1 genotypes.

142 Means followed by the same lower case letter in the column do not differ statistically by the Scott-Knott
143 test at 5% probability.

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145 For the number of eggs, the means were from 114.75 to 2596.25; forming five groups within
146 this range. The reproduction factor had a behavior similar to the number of eggs, since it is
147 directly proportional to this variable. The first group was formed by reproduction factors from
148 0.12 to 0.58; being all the genotypes classified as resistant and presenting the smallest
149 means, being therefore, those indicated for selection. In the second group, composed of
150 reproductive factors from 0.63 to 1.16, individuals with RF <1 and RF > 1 were present.
151 However, because they were statistically different from the first group, which presented the
152 lowest means, genotypes with RF <1 will not be selected. In the other three groups, the
153 reproduction factors were all higher than one, and the selection of such progenies is not
154 recommended.

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156 The RF values of the progenies of group "a" ($0.12 \leq FR \leq 0.58$) were lower than those
157 obtained for the cultivars Verdão (RF = 1.33) and HTV Dom Luiz (RF = 1.71). These
158 progenies also showed smaller RFs than those found by [9], which presented 1.54; 1.59;
159 1.69; 2.01 and 2.42 for the cultivars HTV Dom Luiz, Tapacurá, Verdão, Palmeira and
160 Tabocas, respectively. [11] also obtained a superior result to those found in the present
161 study, where the cultivar Verdão showed RF = 2.4 when inoculated with 1200 eggs of *M.*
162 *incognita* race 1 at 15 days after sowing and evaluated at 45 days after inoculation. Thus,
163 the progenies belonging to the group "a", presented superior behavior regarding the
164 resistance to *M. incognita* race 1, being promising to give continuity to the program of
165 genetic improvement of the culture.

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167 As for the genetic parameters, in all analyzed characters there is a greater contribution of the
168 genetic variation to the variation presented by the phenotype, indicating that there is actually
169 genetic variability among the evaluated progenies, simplifying the selection process and
170 making selection possible (Table 3). This fact is very important because, according to [22],
171 the greater the proportion of variability resulting from the environment in relation to
172 phenotypic variability, the more difficult it is to perform genotype selection effectively,
173 reducing the efficiency of the selective process carried out by the breeder.

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181 **Table 3.** Genetic parameters estimated for the following characters: number of galls in the
 182 root system (NGRS), number of eggs (NE), and reproduction factor (RF).
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Genetic parameters	Characters		
	NGRS	NE	RF
V_g	0.25	107.27	0.107
V_e	0.08	3.64	0.004
V_p	0.33	110.91	0.111
h^2	75.91	96.72	96.70
CV_g	14.97	31.62	31.62
CV_a	16.86	11.62	11.68
CV_g/CV_e	0.89	2.71	2.71

184 Phenotypic variance (V_p), environmental variance (V_e), genetic variance (V_g), heritability (h^2),
 185 coefficient of genetic variance CV_g , coefficient of environmental variance (CV_e), and mean between
 186 coefficient of genetic and environmental variance (CV_g/CV_e).
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188 The coefficients of genetic variation (CV_g) ranged from 31.62 to 14.97 for the reproduction
 189 factor and the number of galls in the root system, respectively. The coefficient of genetic
 190 variation allows inferring about the genetic variability among the characters, and aiding the
 191 selection of superior genotypes for it evidences the levels of genetic variability present in
 192 different genotypes, environment, and characters [23]. Therefore, the estimation of the
 193 genetic variance between family means (progenies) is fundamental and indispensable for
 194 the breeder, since the success of a breeding program depends on the existence of genetic
 195 variability in the work population [12].
 196

197 The heritability presented values from 75.91 (NGRS) to 96.72 (NE), which were considered
 198 high. The attainment of high estimates of heritability indicates that it is possible to select
 199 superior genotypes [5]. Therefore, it is possible to obtain gain with the selection based on
 200 both the number of galls in the system and the number of eggs, and reproduction factor,
 201 based on the data obtained.
 202

203 The heritability values obtained in the present study were higher than those estimated by
 204 [24] in a study carried out for evaluating the cultivars Portuguese, Tabocas, Tapacurá,
 205 Verdão, Palmeira, HTV-9299 parasitized by *M. incognita* race 1, where the estimated
 206 heritability were 48.83 for the number of galls and 70.85 for the number of eggs. Heritability
 207 estimates vary according to several factors such as characteristic; estimation method;
 208 population diversity; endogamy level of the population; evaluated sample size; number and
 209 type of environments considered; experimental unit considered and precision in the
 210 experimental conduction; and data collection [22]. Therefore, even taking into account the
 211 same characteristics in the same species, there will be variation in the values of heritability
 212 obtained in different populations and experiments. In addition, it will be necessary to
 213 estimate such parameter for each working population and to adopt other parameters to
 214 complement the information provided by the heritability, aiming at helping the decision maker
 215 of the breeding, with the CV_g/CV_e ratio being an option to be adopted.
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217 As the CV_g/CV_e ratio was superior to a unit for number of eggs and reproductive factor
 218 (2.71), and close to 1 for the number of galls in the root system (0.89), selection based on
 219 these characters was made possible. This is because, according to [25], there is a favorable
 220 situation to obtain gain with the selection when the CV_g/CV_e ratio tends to 1.0 or is greater
 221 than 1.0 since the genetic variation exceeds the environmental variation. Thus, as the
 222 CV_g/CV_e and heritability are parameters that indicate the success in the selection of
 223 superior genotypes [26], and both parameters obtained in the present study were high, it is
 224 possible to obtain gain in the selection of the superior progenies in the population studied.

225 Moreover, these progenies can be used in the search for genotypes that may be a source of
 226 resistance to *M. incognita* race 1 to be used in breeding programs for coriander.
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228 All genotypes that presented the lowest averages for number of galls in the root system ~~are~~
 229 **were** in the group of **the** lowest values of reproduction factor (0.12 - 0.58). Based on the
 230 correlations between the characters under study, it was verified that all are positively related
 231 to each other (Table 4).
 232

233 **Table 4.** Phenotypic, genetic, and environmental correlation coefficients for the following
 234 characters: number of galls in the root system (NGRS), number of eggs (NE) and
 235 reproduction factor (RF).
 236

Character		NGRS	NE	RF
NGRS	Rp	-	0.71**	0.71**
	Rg	-	0.81**	0.81**
	Re	-	0.23 ^{ns}	0.23 ^{ns}
NE	Rp	-	-	1.0**
	Rg	-	-	1.0**
	Re	-	-	0.99*

237 **Significant at 1% probability by the t test.

238 ^{ns}not significant.

239

240 The phenotypic and genetic correlations between the number of galls in the root system with
 241 the number of eggs and reproductive factor were all significant at 1% probability, being
 242 positive and strong, in the values of 0.81 (NGRS x NE, NGRS x RF) and 0.71 (NGRS x NE;
 243 NGRS x RF) for the genetic and phenotypic correlations, respectively. High genetic
 244 correlation indicates that the characters involved **were** affected by the same genes or are
 245 closely linked genes [27]. This fact is important because it indicates that the indirect
 246 selection based on the number of galls in the root system, a non-destructive mode that
 247 allows recombination of the selected individuals both within and between the progenies, may
 248 be an option to be adopted in the initial selection cycles. Therefore, the reproduction factor is
 249 used as a criterion for selection in more advanced cycles.
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251 The genetic, phenotypic and environmental correlations between the number of eggs and
 252 the reproductive factor were significant at 1% probability. All correlations were very strong
 253 and positive as expected, since the reproduction factor is estimated from the number of
 254 eggs, being directly proportional to this. Although these **were** highly correlated, the use of the
 255 reproductive factor is important because it provides information on the behavior of the
 256 pathogen population. This allows the identification of the genotypes that allow the **nemaode**
 257 population **increase in the soil**, besides allowing the classification of the genotypes as
 258 susceptible and resistant by the scale of [17], optimizing the selective process carried out by
 259 the breeder.
 260

261 4. CONCLUSION

262

263 The inoculation at sowing with 1,000 eggs/cell of *M. incognita* race 1 and evaluation at 30
 264 days after inoculation was efficient in differentiating the evaluated genotypes, promoting
 265 reduction of time and optimization of resources. The selection of superior genotypes, namely
 266 the 12 progenies (67, DP10, 58, 5, 69, 18, DP11, 29, 31, 64, DP6 and 28) indicated for
 267 selection was also made **possibly**.
 268

269 The high values of heritability and CVg/CVe obtained indicate that the number of galls in the
 270 root system, number of eggs, and reproductive factors can be used to make selection of

271 promising genotypes resistant to the pathogen, allowing gain with the selection and
272 attainment of superior bred populations.

273

274 With the strong genetic correlations between the number of galls in the root system and the
275 reproduction factor, it is possible to indicate the selection based on the number of galls in the
276 initial cycles of breeding programs in order to obtain genotypes resistant to *M. incognita* race
277 1 and selection and recombination between and within progenies in the same selective
278 cycle. However, it is indispensable to the extraction of eggs and estimation of the
279 reproduction factor in more advanced cycles in the breeding programs of coriander.

280

281 **COMPETING INTERESTS**

282

283 Authors have declared that there are no competing interests.

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