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Searching for common bean genotypes resistant to *Acanthoscelides obtectus*, a primary pest species of stored beans

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ABSTRACT: Resistant genotypes are a valuable tool in integrated pest management programs of insect pests of stored grains. Here, we screened 90 Brazilian common bean genotypes to select promising sources of resistance to *Acanthoscelides obtectus*. Thus, bean samples were infested with newly emerged insects, and the number of eggs, emerged insects, developmental time, and larval viability were assessed in a no-choice test. Genotypes IPR Garça, CHIR 13, IAC Harmonia, CHIR 20, IAC Boreal, and CHIP 312 showed low oviposition. Genotypes IPR Quero-Quero, BRS Notável, CHIC 61 - Cariocão, BRS Ametista, IPR Uirapuru, IAC Imperador, Avaluna, CHP 04-241A-212 - Guapo B. × Uirapuru, CHIB 06, SCS 206 - Potência, CHC 01-175-1 - Campeiro × IAC Tibatã, CHP 01-182-48 - Uirapuru × Campeiro, UEM 266, CHC 04-233-2 - Siriri × Horizonte, CHV 17-64, SCS 205 - Riqueza, CHP 01-238-80 - MN 13337, SM 1510 - preto, BRS Radiante, CHIB 18, CHIR 14, CAV 17 EFM 008, CHIR 04, IPR Campos Gerais, CHV 05-268-02, LP 13-624 - preto, Linhagem 110 - IAC, CHP 01-182-12 - Uirapuru × Campeiro, LP 13-84 - carioca, BRS Esteio, CHV 17-635, CHB 15-518, Arcelina 1, IPR Tuiuiu, SCS 204 - Predileto, TB - 17-02, BRS Estilo, SM 0511 - cavalo preto, Pérola, IPR Tangará, and CNFRj - 15411 reduced oviposition, the number of emerged adults, and larval viability, suggesting antixenosis and/or antibiosis. Thus, these genotypes are promising sources of resistance factors and can be used in breeding programs to obtain lines of common beans resistant to *A. obtectus*.

Key words: *Phaseolus vulgaris*, bean weevil, host plant resistance, antixenosis, antibiosis.

INTRODUCTION

The common bean, *Phaseolus vulgaris* L. (Fabales: Fabaceae), is a major source of proteins, carbohydrates, vitamins, and minerals (Mendoza and Sánchez 2017). This legume is an important component of human diets both in developing and underdeveloped countries, contributing significantly to the reduction of malnutrition in rural and urban areas, while increasing food security (Nassary et al. 2020, Nadeem et al. 2021, Nchanji and Lutomia 2021). The common bean also has other beneficial biological activities, such as a powerful antioxidant activity due to the high content of polyphenols in its grains (Messina 2014, Celmeli et al. 2018).

Despite its socioeconomic importance, significant amounts of common bean are lost during storage in warehouses, mainly due to the incidence of insect pests (Gonçalves et al. 2015, Adler et al. 2022), because of climatic conditions in tropical regions that favor the development of this biota, in addition to the unsatisfactory storage conditions (Ribeiro et al. 2013).

One of the most serious pests of stored beans worldwide is the bean weevil *Acanthoscelides obtectus* (Say, 1831) (Coleoptera: Chrysomelidae: Bruchinae) (Paul et al. 2009, Thakur 2012, Naroz et al. 2019). The infestation by this bruchid can occur during bean storage or even in the field (Guzzo et al. 2018). In most cases, larvae are carried to warehouses inside the grains infested in the field and, as they develop, the larvae damage the grains mainly by feeding on their internal content. Later, severe losses are detected as consequence of adult emergence. In some cases, the grains are completely destroyed, affecting seed germination and compromising the commercial value of beans because of grain weight reduction and interference on bromatological characteristics (Ishimoto and Chrispeels 1996, Baldin et al. 2017, Mutungi et al. 2020). Moreover, insect-related damage in warehouses, along with inadequate storage devices, compromises food security mainly for smallholder farmers that use the common bean as part of family diet (Endshaw and Hiruy 2020).

The chemical control by synthetic insecticides is the most used method to *A. obtectus* management in warehouses, in addition to curative fumigation (phosphine) and preventative spray of insecticides, mainly pyrethroids and organophosphates (Agrofit 2023). Nevertheless, insecticide overuse and the limited number of products available with different mode of action compromise the strategies of insecticide resistance management, thus increasing the incidence of resistant insect populations (Guedes et al. 2009). Furthermore, there is growing social concern regarding the possible accumulation of chemical residues on treated grains, especially when insecticide applications occur near the time to consume the product (Kljajić et al. 2023). This scenario requires the search for alternative control methods or complementary strategies for integrated pest management programs, such as the development of resistant genotypes (Baldin et al. 2019). Resistant genotypes provide desirable characteristics, such as specificity to the target organism, harmony with the environment, action on successive insect generations, and compatibility with other management tactics used in integrated pest management (Smith and Clement 2012, Baldin et al. 2019).

In the search for resistance sources in *P. vulgaris* genotypes, some studies have detected promising resistant genotypes to *A. obtectus*, indicating different levels of antixenosis and/or antibiosis (Schoonhoven et al. 1983, Cardona et al. 1989, Velten et al. 2007, Zaugg et al. 2012, Guzzo et al. 2015, Baldin et al. 2017). For example, the QUES wild accession showed the lowest *A. obtectus* emergence rates, a smaller number of emerged adults, and longer developmental times (Zaugg et al. 2012). In RAZ lines (arcelin-containing beans), the time until adult emergence was significantly prolonged when compared to susceptible standards and resulted in lower body weight of females (Velten et al. 2007). On the other hand, Cardona et al. (1989) verified that population growth rates of *A. obtectus* were negatively affected by G12952 bean accession. The authors also reported prolonged life cycles, a smaller number of emerged adults, high mortality of late first instars, and reduced female fecundity. In the laboratory, Baldin et al. (2017) identified the genotypes Arc.1, Arc.2, Arc.1S, Arc.5S as resistant to *A. obtectus*, expressing antibiosis by prolonged life cycle and decreased emergence rates. The authors also demonstrated that morphological factors, such as pod surface (chemicals, trichomes, texture) and wall properties (lignified, thickened), are related to antixenosis type resistance observed in Arc.1 and Arc.1S genotypes, in greenhouse tests.

Most studies available, however, were carried out more than a decade ago or investigated a germplasm with restricted genetic variability (some are even currently unavailable), which hinders the use of these sources in breeding programs aiming to obtain resistant genotypes to the bean weevil. In this context, we evaluated the expression of resistance to *A. obtectus* in 90 Brazilian genotypes of *P. vulgaris*, some were evaluated against stored insect pests for the first time. The results of this comprehensive screening are useful for breeding programs to develop lines resistant to the bean weevil.

MATERIAL AND METHODS

Insects

The bean weevils used in the bioassays were obtained from a stock rearing kept in a climatized chamber (25 ± 2°C, relative humidity = 70 ± 10%, and photoperiod of 12:12 h L:D). For colony maintenance, clear glass flasks (800 mL) were used, closed at the top with organdy fabric, allowing internal aeration. Each flask was filled with 300 g of bean grains cv. Bolinha and approximately 100 unsexed adult insects. The grains in the flasks were sieved every 28 days, and the newly emerging adults were used to infest new flasks or in the bioassays proposed.

Bean genotypes

The genotypes studied were obtained from the germplasm banks of the Agronomic Institute of Campinas (IAC) and the Agricultural Research and Rural Extension Company of Santa Catarina. Their respective genealogies, origin, and additional information are described in Table 1. In the bioassays, genotype IAC UNA was included as a susceptible standard (Guzzo et al. 2015, Eduardo et al. 2016).

Table 1. Common bean genotypes evaluated for resistance to *Acanthoscelides obtectus* and their respective genealogy.

Genotype	Germplasm bank	Genealogy/origin/characteristics	Resistance history to bruchids
CHP 01-182-12 - Uirapuru × Campeiro	EPAGRI	Lineage obtained from crossing between IPR Uirapuru and BRS Campeiro	NE
SM 0511 - Cavalo Preto	EPAGRI	No information	NE
SM 1510 - Preto	EPAGRI	No information	NE
LP 13-624 - Preto	EPAGRI	No information	NE
TB-17-02	EPAGRI	No information	NE
TB-17-03	EPAGRI	No information	NE
CHP 01-182-48 - Uirapuru × Campeiro	EPAGRI	Lineage obtained from crossing between IPR Uirapuru and BRS Campeiro	NE
CHP 01-238-80 - MN 13337	EPAGRI	No information	NE
CHP 04-241A-212 - Guapo B × Uirapuru	EPAGRI	Lineage obtained from crossing between Guapo B and Uirapuru	NE
CHP 05-282-04 - Campeiro × Agudo	EPAGRI	Lineage obtained from crossing between Campeiro and Agudo	NE
IPR Campos Gerais	EPAGRI	No information	NE
LP 13-84 - Carioca	EPAGRI	No information	NE
Linhagem 110 - IAC	EPAGRI	No information	NE
FAP-F3-2 SEL - IAC	EPAGRI	No information	NE
LEC 04-16	EPAGRI	No information	NE
UEM 266	EPAGRI	No information	NE
CNFRs - 15558 - Rosinha	EPAGRI	No information	NE
CNFRj - 15411 - Rajado	EPAGRI	No information	NE
CHC 01-175-1 - Campeiro × IAC Tibatã	EPAGRI	Lineage obtained from crossing between BRS Campeiro and IAC Tibatã	NE
CHC 04-233-2 - Siriri × Horizonte	EPAGRI	Lineage obtained from crossing between Siriri and Horizonte	NE
CHIC 61 - Cariocão	EPAGRI	Accession of EPAGRI germplasm bank (“Cariocão”), collected in Campos Novos, SC, Brazil (1997)	NE
BRS Radiante	EMBRAPA	Originated from biparental cross between Pompadour and Iraí	NE
CHIR 04	EPAGRI	Accession of EPAGRI germplasm bank (“Crioulo”), collected in Campos Novos, SC, Brazil (1998)	NE
CHIR 13	EPAGRI	Accession of EPAGRI germplasm bank (“Iraí”), collected in Campos Novos, SC, Brazil (1998)	NE
CHIR 14	EPAGRI	Accession of EPAGRI germplasm bank (“Cavalo criolo”), collected in Campos Novos, SC, Brazil (1997)	NE
CHC 01-167-1-03	EPAGRI	No information	NE
IPR Garça	EPAGRI	No information	NE
CHIB 06	EPAGRI	Lineage obtained from crossing between Ouro Branco and Iraí	NE
CHIB 07	EPAGRI	Lineage of CIAT (EMP 194)	NE
CHIB 11	EPAGRI	Lineage of CIAT (ABA – 19)	NE
CHIB 18	EPAGRI	Crossing lineages CH 05-263-Iraí/Ouro Branco	NE
CHB 15-518	EPAGRI	Crossing lineages CHIB 10/CHIB 18	NE
CHB 15-519	EPAGRI	Crossing lineages CHIB 10/CHIB 47	NE
CHV 05-268-02	EPAGRI	Crossing lineages Amendoim Cavalo/G2333	NE

Continue...

Table 1. Continuation...

Genotype	Germplasm bank	Genealogy/origin/characteristics	Resistance history to bruchids
CHV 17-635	EPAGRI	Lineage obtained from crossing between CHIV 57 and CHIV 76 – F3	NE
CHV 17-641	EPAGRI	Lineage obtained from crossing between CHIV 69 and CHIV 76 – F3	NE
Avaluna	EPAGRI	No information	NE
BRS Campeiro	EMBRAPA	Mutation induction program aiming at altering the color of the tegument of Currente	NE
BRS Esplendor	EMBRAPA	Crossing lineages CB911863/AN9123293	NE
BRS Esteio	EMBRAPA	Crossing lineages FT85 113/POT 51	NE
IPR Tuiuiu	EPAGRI	No information	NE
IPR Uirapuru	EPAGRI	BAC29/PR1711/3/NEP2/2/Puebla 173/Icapijao	NE
SCS 204 - Predileto	EPAGRI	Selected from population MN 13337 introduced from CIAT	NE
SCS 206 - Potência	EPAGRI	No information	NE
BRS Ametista	EMBRAPA	Originated from hybridization of lines PR9115957 and LR720982CP	NE
BRS Estilo	EMBRAPA	Crossing lineages EMP 250 / 4 / A 769 /// A 429 / XAN 252 // V 8025 / PINTO VI 114 (CIAT, 1991)	NE
BRS Notável	EMBRAPA	Crossing lineages A769 / 4 / A774 /// A429 / XAN 252 // V 8025 / G 4449 /// WAF 2 / A 55 // GN 31 / XAN 170	NE
IAC Imperador	EPAGRI	IAC Carioca Eté × Carioca Precoce	NE
IPR Quero-Quero	EPAGRI	No information	NE
IPR Tangará	EPAGRI	LP95-92 × “Pérola”	NE
Pérola	EPAGRI	Selection in “Aporé”	Susceptible (Baldin et al. 2007, Silva et al. 2014)
SCS 205 - Riqueza	EPAGRI	Breeding obtained from breeding of crossing between BRS Campeiro and IAC Tibatã	NE
CAV 17 EFM 0006	EPAGRI	No information	NE
CAV 17 EFM 0007	EPAGRI	No information	NE
CAV 17 EFM 008	EPAGRI	No information	NE
CHIB 12	EPAGRI	Accession of EPAGRI germplasm bank (“Branco Comprido”), collected at the Seed Fair in Canguçu, RS, Brazil (2004)	NE
CHIR 05	EPAGRI	Accession of EPAGRI germplasm bank (“Cavalo mulato”), collected in Guatambu, SC, Brazl (2013)	NE
CHIM 03	EPAGRI	Accession of EPAGRI germplasm bank (“Mourão”), collected in Anchieta, SC, Brazil (2013)	NE
CHIR 20	EPAGRI	Accession of EPAGRI germplasm bank (“Bolinha”), collected in Morro da Fumaça, SC, Brazil (1980s)	NE
CHIM 15	EPAGRI	Accession of EPAGRI germplasm bank (“Mouro”), collected in São Miguel do Oeste, SC, Brazil (1993)	NE
CHIP 347	EPAGRI	Accession of EPAGRI germoplasm bank (“Manteguinha”), collected in União da Vitória, PR, Brazil (1999)	NE
CHIP 346	EPAGRI	Accession of EPAGRI germplasm bank (“Costa Rica”), collected in União da Vitória, PR, Brazil (1999)	NE
CHIP 334	EPAGRI	Accession of EPAGRI germplasm bank (“Crioulo”), collected in Anitápolis, SC, Brazil (1980)	NE
CHC 97-29-07 -Sel. PL. Ind. V 27	EPAGRI	Lineage obtained from plant selection within access of Epagri germplasm bank	NE
CHC 98-42-IAC Eté × FEB 189 F9	EPAGRI	Lineage obtained from crossing between IAC Eté and lineage of CIATFEB 183	NE
CHC 00-101-10 Pérola × IAC F8	EPAGRI	Lineage obtained from crossing between Pérola and IAC Eté	NE
CHC 01-175-2 Campeiro × Tiba F11	EPAGRI	Lineage obtained from crossing between BRS Campeiro and IAC Tibatã	NE
CHIP 175	EPAGRI	Accession of EPAGRI germplasm bank, collected in Chapecó, SC, Brazil (collected in the 1980s)	NE

Continue...

Table 1. Continuation...

Genotype	Germplasm bank	Genealogy/origin/characteristics	Resistance history to bruchids
CHIP 283	EPAGRI	Accession of EPAGRI germplasm bank (“Bolinha”), collected in União da Vitória, PR, Brazil (1999)	NE
CHIP 305	EPAGRI	Accession of EPAGRI germplasm bank (“Topixaba”), collected in União da Vitória, PR, Brazil (1999)	NE
CHIP 312	EPAGRI	Accession of EPAGRI germplasm bank, collected in Alfredo Wagner, SC, Brazil (collected in 1980s)	NE
ANFc09	Agro Norte Pesquisa e Sementes LTDA	No information	NE
IAC Formoso	IAC	Gen 96A28P4-1-1-1-1 × CNFC9484	NE
IAC Diplomata	IAC	No information	NE
Arcelina 3	IAC	Source of resistance to bruchids	Antixenosis (Baldin and Pereira 2010)
IAC Alvorada	IAC	Wonderful. G2338 (IAC Maravilha.And277) × L317-1	Susceptible (Eduardo et al. 2016)
IPR Siriri	IAC	Crossing between cultivars IAPAR 31 and IAC Akitã	NE
Arcelina 1	IAC	Source of resistance to bruchids	Antixenosis (Baldin and Pereira 2010); Antibiosis (Eduardo et al. 2016)
IAC Jabola	IAC	Access Jabola Bag IAC × IAC Tybatã	NE
IAC UNA*	IAC	Source of anthracnose resistance (Dor 41 × H1178-100)	Susceptible (Guzzo et al. 2015)
IAC Boreal	IAC	IAC Carioca Aruã × CAL 143	NE
IAC Harmonia	IAC	IAC Carioca Aruã × Iraí	Antixenosis (Costa et al. 2013)
CHIP 295	EPAGRI	No information	NE
CHIP 315	EPAGRI	No information	NE
CHIP 282	EPAGRI	No information	NE
CHP 01-238-10	EPAGRI	No information	NE
CHP 04-239-S2	EPAGRI	No information	NE
CHIN 19	EPAGRI	No information	NE
CHIP 297	EPAGRI	No information	NE
S 04-230-2	EPAGRI	No information	NE

NE: not evaluated; *genotype included as a susceptible standard; EPAGRI: Agricultural Research and Rural Extension Company of Santa Catarina; IAC: Agronomic Institute of Campinas; EMBRAPA: Brazilian Agricultural Research Corporation.

Bioassays

Transparent acrylic containers of 50 mL (experimental units) with lids (5 cm height × 3 cm diameter) were used to accommodate 5 g of bean grains from each genotype tested. The grains were weighed on an analytical balance at the accuracy of 0.001 g. Afterward, 10 unsexed adults with ages between 0–48 h, randomly collected from the stock rearing, were released into each container for oviposition for seven days (Baldin and Lara 2008). The difference between male and female is observed from the inclination of the pygidium, vertical in males and oblique in females (Athié and Paula 2002), and the sex ratio of the species is 1:1 of male and female (Howe and Currie 1964). Thus, unsexed adults were used in the initial screening due to the large number of genotypes tested and the difficulty of sexing.

After preparation and insect infestation, the experimental units were stored in a biochemical oxygen demand chamber (25 ± 2°C, relative humidity = 70 ± 10%, and photoperiod of 12:12 h L:D). After seven days, adults were removed, and the number of total eggs, viable eggs, and non-viable eggs were counted at 21 days after infestation with the aid of a stereoscopic microscope (40x magnifications). The grains of each plot were deposited in Petri dishes (90 × 15 mm) covered with black cardboard to facilitate visualization of the eggs deposited between the grains. Viable eggs had a larval exit hole, while non-viable eggs were intact with a hyaline coloration aspect (Ribeiro-Costa et al. 2007).

Twenty-eight days after the initial infestation, the number of emerged insects and the developmental time (egg-adult) were also determined by sieving the grains of each container through an appropriate mesh and by counting the number of insects emerging per day and per genotype, until there were no more emergences for five consecutive days. The weighted mean calculated by the Eq. 1 was used to determine the egg-to-adult developmental time.

$$\sum xf / \sum x \tag{1}$$

where: x: the number of adults emerging in that day; f: the number of emergence days (Costa and Boiça Júnior 2004).

Larval viability was calculated based on the number of viable eggs and the number of emergences per genotype. The experimental design was completely randomized with four repetitions per genotype. Each container with 5 g of grains and 10 insects was considered as a repetition.

Statistical analysis

For the data analysis, we first verified the normality of residues with the Shapiro-Wilk test (Shapiro and Wilk 1965), as well as the homogeneity of variances with the Levene test (Levene 1960). When assumptions were satisfied, the data were submitted to the analysis of variance, and the means were compared by the Scott-Knott test ($p < 0.05$). The statistical software Statistical Analysis System (version 9.2) was used for the analyses.

The multivariate cluster analysis was performed to verify the grouping of the genotypes studied using the following variables: larval viability (%), number of emerged adults, developmental time, and total number of eggs. The mean Euclidean distance, as a measure of dissimilarity, and the average method as a clustering strategy were used because they had the highest co-optic correlation (Manly 2004). The cut-off was established considering half of the maximum adjusted Euclidian distance (Fávero and Belfiore 2017).

RESULTS

There was significant variation in oviposition of *A. obtectus* between the different bean genotypes studied (Table 2). Regarding the total number of eggs, genotypes BRS Notável, IPR Quero-Quero, BRS Ametista, IPR Uirapuru, Linhagem 110 - IAC, Avaluna, IAC Imperador, CHIB 06, SCS 206 - Potência, CHIC 61 - Cariocão, IPR Tangará, CHIR 13, CHP 04-241A-212 - Guapo B. × Uirapuru, Pérola, CNFRj - 15411 - Rajado, CHC 04-233-2 - Siriri × Horizonte, CHP 01-182-48 - Uirapuru × Campeiro, CHC 01-175-2 Campeiro × Tiba F11, UEM 266, CHC 01-175-1 - Campeiro × IAC Tibatã, SCS 204 - Predileto, LP 13-84 - Carioca, TB - 17-02, IPR Garça, BRS Esteio, CHIP 283, BRS Estilo, Arcelin 1, SM 0511 - Cavalo Preto, CHP 01-182-12 - Uirapuru × Campeiro, IPR Tuiuiu, CHIP 295, CHV 17-635, IAC Boreal, CHIR 20, CHIP 315, CHB 15-518, CAV 17 EFM 0007, CHC 00-101-10 Pérola × IAC F8, CAV 17 EFM 008, CHV 17-641, CHIM 15, CHIR 14, Arcelin 3, and CHIB 11 were the less oviposited (between 15.75 and 75.50 eggs/sample; Table 2). These genotypes had lower oviposition compared to genotype IAC UNA, used as a susceptible standard, and were chosen based on the studies of Guzzo et al. (2015) and Eduardo et al. (2016) (Table 2). The same genotypes with the smallest means of total eggs also had the smallest means of viable eggs (Table 2); however, there was no significant difference between all genotypes tested in terms of the number of unviable eggs (Table 2).

Table 2. Means (± standard error) of number of total eggs, viable eggs, unviable eggs, emerged adults, larval viability (%) and developmental time (days) of *Acanthoscelides obtectus* in different common bean genotypes[1].

Genotype	Total number of eggs	Number of viable eggs	Number of unviable eggs	Number of emerged adults	Larval viability (%)	Developmental time
BRS Notável	15.75 ± 5.44 b	12.75 ± 4.71 b	3.00 ± 0.82	3.25 ± 2.29 b	20.22 ± 10.19 b	32.40 ± 1.33 b
IPR Quero-Quero	24.25 ± 6.79 b	20.75 ± 4.96 b	3.50 ± 2.25	3.25 ± 1.44 b	19.37 ± 7.78 b	33.14 ± 0.81 b
BRS Ametista	33.00 ± 8.01 b	27.75 ± 8.44 b	5.25 ± 1.03	2.25 ± 1.11 b	22.02 ± 16.76 b	34.50 ± 0.50 b
IPR Uirapuru	33.25 ± 4.61 b	31.75 ±4.39 b	1.50 ± 0.65	5.25 ± 3.20 b	18.15 ± 11.74 b	35.63 ± 0.06 a
Linhagem 110 - IAC	36.00 ± 7.33 b	31.00 ± 7.04 b	5.00 ± 1.78	12.50 ± 3.28 b	40.13 ± 4.56 a	31.98 ± 0.42 b
Avaluna	37.25 ± 7.58 b	26.00 ± 5.72 b	11.25 ± 2.39	5.50 ± 3.66 b	18.04 ± 9.01 b	34.56 ± 0.49 b
IAC Imperador	38.50 ± 13.56 b	28.00 ± 8.22 b	10.50 ± 5.78	5.25 ± 2.63 b	17.08 ± 4.15 b	33.41 ± 0.92 b
CHIB 06	40.25 ± 2.87 b	34.75 ± 2.95 b	5.50 ± 0.96	3.50 ± 1.32 b	9.61 ± 3.11 b	35.37 ± 0.83 a
SCS 206 - Potência	41.25 ± 9.03 b	33.25 ± 6.25 b	8.00 ± 3.11	3.50 ± 1.66 b	9.85 ± 3.67 b	32.16 ± 0.73 b
CHIC 61 - Cariocão	42.50 ± 12.32 b	35.25 ± 11.40 b	7.25 ± 1.11	7.25 ± 2.81 b	16.93 ± 7.03 b	35.22 ± 0.68 a
IPR Tangará	43.50 ± 22.20 b	34.25 ± 15.76 b	9.25 ± 7.04	11.00 ± 5.85 b	25.33 ± 9.49 b	35.06 ± 0.20 a
CHIR 13	44.25 ± 14.20 b	38.75 ± 13.51 b	5.50 ± 1.04	32.50 ± 11.88 a	65.45 ± 22.00 a	36.53 ± 2.02 a
CHP 04-241A-212 - Guapo B. × Uirapuru	44.75 ± 18.87 b	29.00 ± 10.45 b	15.75 ± 8.50	2.00 ± 0.71 b	8.43 ± 2.60 b	33.75 ± 2.49 b
Pérola	45.25 ± 16.25 b	43.75 ± 15.80 b	1.50 ± 0.65	21.00 ± 11.57 b	34.20 ± 15.28 b	31.13 ± 1.11 b
CNFRj - 15411 - Rajado	47.00 ± 4.42 b	42.25 ± 4.48 b	4.75 ± 2.25	12.50 ± 3.40 b	32.55 ± 11.22 b	35.15 ± 1.53 a
CHC 04-233-2 - Siriri × Horizonte	47.50 ± 16.52 b	44.75 ± 15.84 b	2.75 ± 1.25	6.75 ± 4.37 b	11.57 ± 6.30 b	33.75 ± 0.83 b
CHP 01-182-48 - Uirapuru × Campeiro	47.75 ± 4.31 b	43.00 ± 3.34 b	4.75 ± 1.55	3.00 ± 1.58 b	7.67 ± 4.16 b	37.60 ± 0.95 a
CHC 01-175-2 Campeiro × Tiba F11	50.25 ± 18.76 b	38.25 ± 13.77 b	12.00 ± 6.75	24.75 ± 20.48 b	46.04 ± 29.95 b	33.17 ± 0.91 b
UEM 266	51.00 ± 13.48 b	46.50 ± 13.42 b	4.50 ± 0.96	3.50 ± 0.65 b	8.97 ± 1.87 b	33.40 ± 1.39 b
CHC 01-175-1 - Campeiro × IAC Tibatã	51.00 ± 15.24 b	47.75 ± 14.82 b	3.25 ± 0.75	2.00 ± 0.91 b	5.47 ± 3.17 b	38.33 ± 2.01 a
SCS 204 - Predileto	51.00 ± 23.82 b	49.00 ± 23.05 b	2.00 ± 0.91	18.75 ± 11.71 b	27.84 ± 10.73 b	35.33 ± 0.45 a
LP 13-84 - Carioca	52.75 ± 26.96 b	44.50 ± 23.46 b	8.25 ± 4.31	8.00 ± 2.48 b	23.83 ± 9.24 b	36.55 ± 1.47 a
TB - 17-02	53.00 ± 2.42 b	48.50 ± 3.77 b	4.50 ± 1.55	14.50 ± 6.96 b	28.08 ± 11.50 b	32.03 ± 0.63 b
IPR Garça	53.50 ± 7.80 b	51.25 ± 7.00 b	2.25 ± 1.31	28.25 ± 6.79 a	64.58 ± 24.13 a	34.48 ± 0.53 b
BRS Esteio	53.50 ± 11.26 b	48.75 ± 10.14 b	4.75 ± 1.18	10.25 ± 4.13 b	26.09 ± 11.22 b	33.97 ± 0.74 b
CHIP 283	54.75 ± 6.02 b	48.25 ± 4.03 b	6.50 ± 2.87	24.50 ± 4.57 a	49.73 ± 6.95 a	33.03 ± 0.24 b
BRS Estilo	55.25 ± 16.10 b	48.00 ± 14.44 b	7.33 ± 2.85	15.25 ± 1.14 b	27.75 ± 17.94 b	34.82 ± 0.66 a
Arcelina 1	55.75 ± 17.83 b	48.75 ± 16.54 b	7.00 ± 1.47	18.25 ± 6.32 b	30.96 ± 10.82 b	37.72 ± 2.26 a
SM 0511 - Cavalo Preto	56.75 ± 9.34 b	52.00 ± 9.93 b	4.75 ± 2.43	15.25 ± 5.51 b	31.15 ± 8.62 b	34.53 ± 1.00 b
CHP 01-182-12 - Uirapuru × Campeiro	58.50 ± 14.77 b	53.75 ± 16.19 b	4.75 ± 1.89	13.75 ± 6.30 b	20.22 ± 9.16 b	34.31 ± 1.46 b

Continue...

Table 2. Continuation...

Genotype	Total number of eggs	Number of viable eggs	Number of unviable eggs	Number of emerged adults	Larval viability (%)	Developmental time
IPR Tuiuiu	58.75 ± 8.08 b	55.50 ± 7.24 b	3.25 ± 1.25	19.25 ± 9.55 b	32.09 ± 13.15 b	35.85 ± 0.71 a
IAC Harmonia	60.25 ± 27.83 b	39.00 ± 18.48 b	21.25 ± 11.28	19.25 ± 8.12 b	73.02 ± 17.81 a	32.95 ± 1.33 b
CHIP 295	61.00 ± 12.73 b	55.75 ± 11.56 b	5.25± 1.75	28.00 ± 12.36 a	43.73 ± 15.44 a	32.34 ± 0.79 b
CHV 17-635	61.00 ± 30.62 b	52.50 ± 30.06 b	8.50 ± 2.53	11.25 ± 4.03 b	28.79 ± 15.95 b	34.89 ± 0.93 a
IAC Boreal	61.50 ± 21.98 b	56.00 ± 20.24 b	5.50 ± 2.53	50.33 ± 14.57 a	65.79 ± 14.11 a	26.71 ± 6.26 b
CHIR 20	62.00 ± 16.58 b	52.00 ± 16.06 b	10.00 ± 1.73	31.50 ± 60.06 a	79.48 ± 20.99 a	33.35 ± 0.74 b
CHIP 315	62.50 ± 16.64 b	56.25 ± 14.52 b	6.25 ± 3.12	28.00 ± 12.99 a	40.32 ± 12.38 a	32.85 ± 1.20 b
CHB 15-518	63.25 ± 15.93 b	55.75 ± 13.33 b	7.50 ± 2.63	12.75 ± 4.77 b	29.50 ± 11.78 b	36.03 ± 0.65 a
CAV 17 EFM 0007	63.75 ± 6.09 b	59.25 ± 5.54 b	4.50 ± 0.96	23.00 ± 3.54 a	39.69 ± 6.64 a	33.31 ± 0.19 b
CHC 00-101-10 Pérola × IAC F8	63.75 ± 8.59 b	54.75 ± 6.79 b	9.00 ± 1.96	28.25 ± 5.19 a	50.69 ± 6.79 a	34.14 ± 1.08 b
CAV 17 EFM 008	65.25 ± 12.86 b	57.25 ± 12.57 b	8.00 ± 3.11	13.75 ± 6.18 b	21.38 ± 7.13 b	32.99 ± 0.33 b
CHIP 312	68.00 ± 6.77 a	65.50 ± 6.12 a	2.50 ± 0.96	57.00 ± 6.01 a	89.00 ± 11.12 a	33.98 ± 0.21 b
CHIR 04	68.00 ± 10.26 a	63.25 ± 9.99 a	4.75 ± 2.43	13.00 ± 4.81 b	25.41 ± 11.79 b	33.58 ± 0.60 b
CHIP 305	68.25 ± 10.72 a	61.75 ± 9.23 a	6.50 ± 2.90	36.25 ± 15.21 a	54.57 ± 16.09 a	35.42 ± 2.40 a
CHIB 18	68.75 ± 17.72 a	62.25 ± 15.12 a	6.50 ± 3.93	14.25 ± 5.11 b	21.66 ± 3.71 b	35.93 ± 0.55 a
CHV 17-641	70.25 ± 33.14 b	65.50 ± 30.36 b	4.75 ± 3.54	9.50 ± 3.93 b	18.11 ± 10.19 b	35.51 ± 0.62 a
CHIM 15	70.25 ± 39.18 b	63.50 ± 37.09 b	6.75 ± 2.50	28.25 ± 16.03 b	30.80 ± 14.79 b	32.69 ± 1.89 b
CHP 01-238-10	70.75 ± 11.73 a	65.75 ± 12.03 a	5.00 ± 0.91	27.75 ± 10.00 a	38.59 ± 9.96 a	33.69 ± 0.76 b
CHIR 14	71.00 ± 33.28 b	67.00 ± 31.00 b	4.00 ± 2.74	16.50 ± 8.54 b	22.42 ± 7.94 b	35.87 ± 1.63 a
SCS 205 - Riqueza	72.50 ± 20.18 a	69.75 ± 18.65 a	2.75 ± 1.55	12.50 ± 5.30 b	18.34 ± 4.90 b	32.74 ± 0.96 b
Arcelina 3	72.75 ± 35.17 b	66.25 ± 35.75 b	6.50 ± 0.65	25.00 ± 14.70 b	31.40 ± 12.40 b	35.65 ± 0.29 a
BRS Radiante	73.25 ± 15.59 a	69.25 ± 14.61 a	4.00 ± 1.22	17.50 ± 8.23 b	22.20 ± 5.45 b	33.39 ± 0.72 b
SM 1510 - Preto	74.00 ± 1.47 a	65.75 ± 3.75 a	8.25 ± 3.64	10.50 ± 2.33 b	16.20 ± 3.75 b	34.89 ± 0.75 a
CHP 01-238-80 - MN 13337	74.25 ± 29.03 a	69.25 ± 28.02 a	5.00 ± 2.04	12.50 ± 8.18 b	15.64 ± 4.44 b	32.62 ± 0.87 b
CHIB 11	74.50 ± 57.72 b	66.25 ± 49.90 b	8.25 ± 7.92	19.75 ± 13.00 b	34.92 ± 17.07 b	30.35 ± 2.31 b
CHC 98-42-IAC Eté × FEB 189 F9	76.25 ± 29.23 a	63.50 ± 14.09 a	12.75 ± 6.14	34.50 ± 18.71 a	48.90 ± 18.79 a	33.68 ± 0.71 b
LEC 04-16	78.50 ± 14.53 a	72.50 ± 16.88 a	6.00 ± 2.68	33.75 ± 10.66 a	47.26 ± 12.32 a	33.58 ± 0.20 b
CHIP 347	79.00 ± 15.68 a	70.00 ± 13.15 a	9.00 ± 4.55	31.25 ± 7.87 a	44.17 ± 10.30 a	36.54 ± 3.48 a
IAC Diplomata	79.00 ± 38.23 a	72.00 ± 34.20 a	7.00 ± 4.38	25.75 ± 14.14 a	38.58 ± 10.76 a	35.23 ± 3.26 a
IPR Campos Gerais	81.75 ± 13.14 a	73.00 ± 9.96 a	8.75 ± 4.91	11.50 ± 2.47 b	15.60 ± 2.36 b	36.26 ± 2.77 b
LP 13-624 - Preto	83.00 ± 12.89 a	74.75 ± 12.91 a	8.25 ± 1.65	17.50 ± 4.91 b	24.37 ± 7.50 b	34.18 ± 0.40 b
CHIB 12	83.50 ± 11.68 a	71.00 ± 14.51 a	12.50 ± 5.69	43.50 ± 11.11 a	65.06 ± 19.02 a	35.20 ± 0.49 a
IAC UNA	84.75 ± 24.67 a	64.75 ± 21.61 a	20.00 ± 15.76	34.50 ± 11.93 a	56.91 ± 8.44 a	34.23 ± 0.79 b
CHV 05-268-02	85.00 ± 16.22 a	68.50 ± 18.81 a	16.50 ± 7.04	14.25 ± 4.21 b	23.78 ± 7.50 b	33.89 ± 0.76 b
CHIP 334	85.50 ± 17.17 a	77.00 ± 17.08 a	8.50 ± 2.47	38.75 ± 10.40 a	50.94 ± 10.88 a	33.48 ± 0.35 b
CHC 04230-2	85.50 ± 29.01 a	76.25 ± 26.34 a	9.25 ± 3.25	45.50 ± 18.10 a	53.65 ± 6.70 a	34.37 ± 1.65 b
CNFRs - 15558 - Rosinha	88.00 ± 19.76 a	75.75 ± 14.13 a	12.25 ± 5.91	31.25 ± 10.64 a	45.88 ± 18.38 a	32.77 ± 1.12 b
CHP 05-282-04 - Campeiro × Agudo	88.50 ± 32.46 a	82.00 ± 29.00 a	6.50 ± 3.52	6.00 ± 2.08 b	7.27 ± 1.90 b	33.29 ± 0.18 b
CHIM 03	90.25 ± 21.71 a	85.75 ± 19.97 a	4.50 ± 1.94	51.75 ± 8.32 a	64.55 ± 10.11 a	34.37 ± 0.31 b
CHIR 05	90.50 ± 17.72 a	83.75 ± 16.80 a	6.75 ± 1.44	52.25 ± 8.53 a	67.47 ± 10.08 a	34.50 ± 0.59 b
CHC 01-167-1-03	91.25 ± 29.75 a	81.25 ± 24.37 a	10.00 ± 5.70	6.25 ± 1.49 b	8.07 ± 0.54 b	34.39 ± 1.18 b
CHIP 175	92.00 ± 24.15 a	64.00 ± 10.26 a	28.00 ± 22.80	29.25 ± 12.37 a	44.84 ± 17.63 a	37.09 ± 2.61 a
TB - 17-03	94.75 ± 41.16 a	85.00 ± 36.35 a	9.75 ± 5.20	12.75 ± 5.54 b	11.88 ± 5.40 b	36.56 ± 3.01 a
ANFc09	95.00 ± 27.70 a	73.50 ± 20.66 a	21.50 ± 7.66	50.25 ± 17.57 a	55.67 ± 20.47 a	35.75 ± 0.14 a
CHB 15-519	95.5 ± 22.15 a	87.75 ± 21.45 a	7.75 ± 2.17	29.75 ± 12.44 a	31.81 ± 6.79 a	35.80 ± 0.91 a

Continue...

Table 2. Continuation...

Genotype	Total number of eggs	Number of viable eggs	Number of unviable eggs	Number of emerged adults	Larval viability (%)	Developmental time
IAC Jabola	96.00 ± 29.62 a	92.75 ± 28.33 a	3.25 ± 1.31	29.25 ± 6.84 a	37.73 ± 10.05 a	34.04 ± 0.86 b
FAP-F3-2 SEL - IAC	96.25 ± 37.93 a	83.00 ± 29.56 a	13.25 ± 8.66	21.75 ± 5.07 a	36.22 ± 10.06 a	33.22 ± 0.96 b
IAC Formoso	101.00 ± 15.22 a	89.00 ± 20.80 a	12.00 ± 4.97	51.25 ± 14.70 a	55.35 ± 4.09 a	33.23 ± 1.15 b
CHIP 346	101.25 ± 24.54 a	82.75 ± 22.38 a	18.50 ± 8.68	39.00 ± 11.45 a	44.59 ± 10.35 a	32.77 ± 1.48 b
CHIB 07	102.00 ± 17.49 a	100.00 ± 17.49 a	2.00 ± 0.00	6.50 ± 2.90 b	8.67 ± 4.54 b	35.30 ± 1.16 a
CAV 17 EFM 0006	102.75 ± 28.58 a	97.25 ± 27.77 a	5.50 ± 1.55	24.00 ± 14.90 b	18.18 ± 8.81 b	36.11 ± 0.81 a
CHIN 19	104.50 ± 21.33 a	89.75 ± 20.79 a	14.75 ± 8.59	56.00 ± 6.56 a	66.90 ± 8.50 a	33.60 ± 0.69 b
CHP 04-239-S2	105.25 ± 21.77 a	94.25 ± 19.77 a	11.00 ± 5.18	47.00 ± 12.10 a	54.28 ± 12.76 a	34.46 ± 1.12 b
IAC Alvorada	105.75 ± 12.63 a	87.50 ± 9.90 a	18.25 ± 4.05	45.75 ± 11.19 a	53.16 ± 10.94 a	34.47 ± 0.50 b
IPR Siriri	106.75 ± 13.84 a	95.50 ± 12.22 a	11.25 ± 4.21	23.75 ± 5.45 a	28.49 ± 10.83 b	39.25 ± 3.19 a
BRS Esplendor	110.00 ± 35.94 a	80.75 ± 25.83 a	29.25 ± 11.43	5.00 ± 3.00 b	8.19 ± 4.78 b	36.44 ± 0.72 a
CHIP 282	112.25 ± 26.61 a	101.50 ± 20.99 a	10.75 ± 8.76	36.25 ± 11.90 a	31.97 ± 6.47 a	33.40 ± 1.16 b
CHIP 297	115.25 ± 44.08 a	97.75 ± 44.20 a	17.50 ± 0.65	48.00 ± 27.08 a	44.56 ± 12.98 a	33.39 ± 0.77 b
BRS Campeiro	124.50 ± 11.51 a	108.75 ± 12.15 a	15.75 ± 2.14	17.50 ± 12.34 b	14.43 ± 8.80 b	34.86 ± 1.52 a
CHC 97-29-07 -Sel. PL. Ind. V 27	140.25 ± 26.75 a	130.25 ± 27.75 a	10.00 ± 5.35	57.75 ± 11.08 a	52.57 ± 14.26 a	34.05 ± 0.56 b
F	1.3501	1.3898	1.2565	2.7074	2.3560	1.7207
df	89, 270	89, 270	89, 270	89, 270	89, 270	89, 270
p-value	0.03552	0.02381	0.08496^{ns}	< 0.0001	< 0.0001	0.00048

[1] Means within the columns followed by the same letters are not significantly different by the Skott-Knott test ($p < 0.05$). Original data presented in the table. For the analysis, data were transformed using the optimal power method of Box and Cox (1964), were $\lambda = 0.45$ (total number of eggs); $\lambda = 0.45$ (number of viable eggs); $\lambda = 0$ (number of unviable eggs); $\lambda = 0.25$ (number of emerged adults); $\lambda = 0.45$ (larval viability); $\lambda = 1.45$ (developmental time); ^{ns}not significant; df: degrees of freedom.

Genotypes BRS Notável, IPR Quero-Quero, BRS Ametista, IPR Uirapuru, Linhagem 110 - IAC, Avaluna, IAC Imperador, CHIB 06, SCS 206 - Potência, CHIC 61 - Cariocão, IPR Tangará, CHP 04-241A-212 - Guapo B. × Uirapuru, Pérola, CNFRj - 15411 - Rajado, CHC 04-233-2 - Siriri × Horizonte, CHP 01-182-48 - Uirapuru × Campeiro, CHC 01-175-2 Campeiro × Tiba F11, UEM 266, CHC 01-175-1 - Campeiro × IAC Tibatã, SCS 204 - Predileto, LP 13-84 - Carioca, TB -17-02, BRS Esteio, BRS Estilo, Arcelin 1, SM 0511 - Cavalo Preto, CHP 01-182-12 - Uirapuru × Campeiro, IPR Tuiuiu, IAC Harmonia, CHV 17-635, CHB 15-518, CAV 17 EFM 008, CHIR 04, CHIB 18, CHV 17-641, CHIM 15, CHIR 14, SCS 205 - Riqueza, Arcelina 3, BRS Radiante, SM 1510 - Preto, CHP 01-238-80 - MN 13337, CHIB 11, IPR Campos Gerais, LP 13-624 - Preto, CHV 05-268-02, CHP 05-282-04 - Campeiro × Agudo, CHC 01-167-1-03, TB - 17-03, CHIB 07, CAV 17 EFM 0006, BRS Esplendor, and BRS Campeiro showed a significant reduction in the number of emerged adults (between 2 and 28.25 adults/sample). The remaining genotypes showed high emergence in comparison to most susceptible genotypes, as well as a similar behavior to the genotype adopted as a susceptible standard (IAC UNA) (Table 2).

The same genotypes with lower averages of emerged adults showed low percentage of larval viability (%), in addition to genotypes IPR Siri and excluding IAC Harmonia (Table 2). Genotypes IPR Uirapuru, CHIB 06, CHIC 61 - Cariocão, IPR Tangará, CHIR 13, CNFRj - 15411 - Rajado, CHP 01-182-48 - Uirapuru × Campeiro, CHC 01-175-1 - Campeiro × IAC Tibatã, SCS 204 - Predileto, LP 13-84 - Carioca, BRS Estilo, Arcelin 1, IPR Tuiuiu, CHV 17-635, CHB 15-518, CHIP 305, CHIB 18, CHV 17-641, CHIR 14, Arcelin 3, SM 1510 - Preto, CHIP 347, IAC Diplomata, CHIB 12, CHIP 175, TB - 17-03, ANFc09, CHB 15-519, CHIB 07, CAV 17 EFM 0006, IPR Siriri, BRS Esplendor, and BRS Campeiro showed the largest means for the developmental time (egg-to-adult period) (between 34.82 and 39.25 days), differing from the other genotypes tested, including the IAC UNA susceptible standard (Table 2).

The multivariate cluster analysis resulted in five groups using the variables of larval viability, number of adults emerged, developmental time, and total number of eggs, as well as half of maximum Euclidean distance adjusted as a cut-off point (Fávero and Belfiore 2017) (Fig. 1).

Group I was the most distinct and was composed only of genotype CHC 97-29-07 - Sel PL. Ind. V2, which exhibited the largest means in all parameters evaluated and behaved as the most susceptible genotype. Group II was the most inclusive, with 41 genotypes (IPR Quero-Quero, BRS Notável, CHIC 61 - Cariocão, BRS Ametista, IPR Uirapuru, IAC Imperador, Avaluna, CHP 04-241A-212 - Guapo B. × Uirapuru, CHIB 06, SCS 206 - Potência, CHC 01-175-1 - Campeiro × IAC Tibatã, CHP 01-182-48 - Uirapuru × Campeiro, UEM 266, CHC 04-233-2 - Siriri × Horizonte, CHV 17-64, SCS 205 - Riqueza, CHP 01-238-80 - MN 13337, SM 1510 - Preto, BRS Radiante, CHIB 18, CHIR 14, CAV 17 EFM 008, CHIR 04, IPR Campos Gerais, CHV 05-268-02, LP 13-624 - Preto, Linhagem 110 - IAC, CHP 01-182-12 - Uirapuru × Campeiro, LP 13-84 - Carioca, BRS Esteio, CHV 17-635, CHB 15-518, Arcelina 1, IPR Tuiuiu, SCS 204 - Predileto, TB - 17-02, BRS Estilo, SM 0511 - Cavalo Preto, Pérola, IPR Tangará and CNFRj - 15411), congregating the genotypes with the lowest oviposition and smallest number of emerged insects and consequently lower means of larval viability.

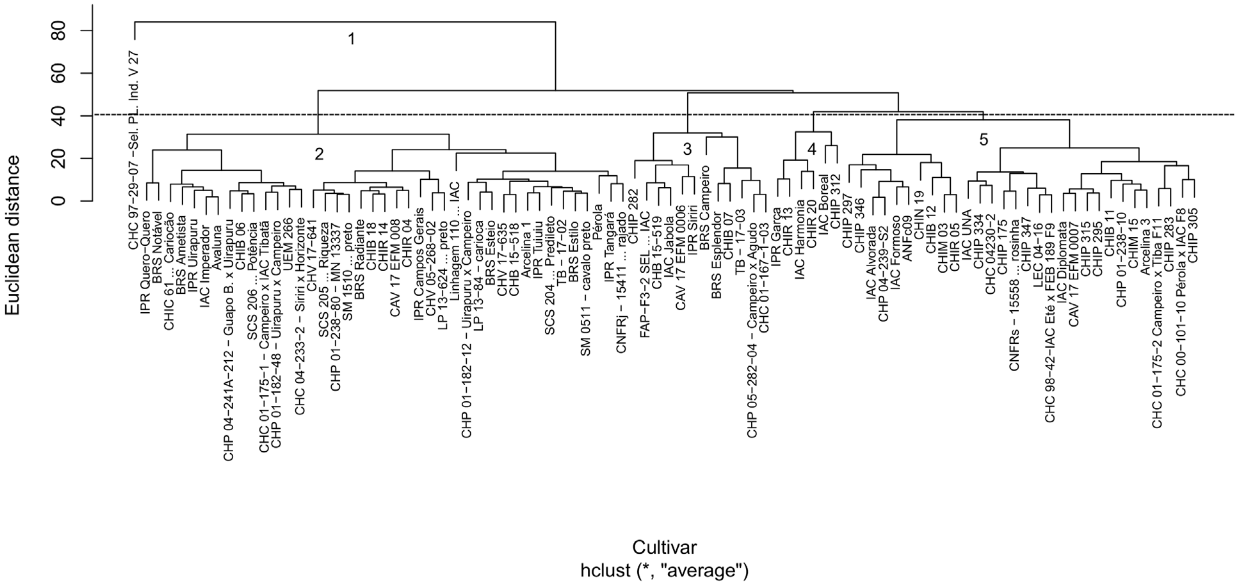

Figure 1. Dendrogram obtained from the cluster analysis based on similarity of biological parameters (larval viability, number of emerged adults, developmental time, and total number of eggs) of *Acanthoscelides obtectus* on common bean (*Phaseolus vulgaris* L., Fabaceae) genotypes. The mean Euclidean distance was used as a measure of dissimilarity and the average method as a clustering strategy [the cut-off was established considering half of maximum adjusted Euclidian distance (41); (dashed line)].

On the other hand, group III was represented by genotypes CHIP 282, FAP-F3-2 SEL - IAC, CHB 15-519, IAC Jabola, CAV 17 EFM 0006, IPR Siriri, BRS Campeiro, BRS Esplendor, CHIB 07, TB - 17-03, CHP 05-282-04 - Campeiro × Agudo and CHC 01-167-1-03, which exhibited a larger number of eggs. Group IV congregated genotypes IPR Garça, CHIR 13, IAC Harmonia, CHIR 20, IAC Boreal and CHIP 312, grouping the genotypes with the shortest developmental time and lowest oviposition. Conversely, these materials showed larger means of emerged adults and larval viability (%).

Finally, group V was composed by genotypes CHIP 297, CHIP 346, IAC Alvorada, CHP 04-239-S2, IAC Formoso, ANFc09, CHIN 19, CHIB 12, CHIM 03, CHIR 05, IAC UNA (susceptible standard), CHIP 334, CHC 04230-2, CHIP 175, CNFRs - 15558 - Rosinha, CHIP 347, LEC 04-16, CHC 98-42-IAC Eté × FEB 189 F9, IAC Diplomata, CAV 17 EFM 0007, CHIP 315, CHIP 295, CHIB 11, CHP 01-238-10, CHIM 15, Arcelin 3, CHC 01-175-2 Campeiro × Tiba F11, CHIP 283, CHC 00-101-10 Pérola × IAC F8, and CHIP 305 congregated genotypes with the highest oviposition rates, the largest number of emerged adults, and the highest larval viability. In contrast, these genotypes showed the lowest developmental time.

DISCUSSION

Our comprehensive screening with a diversified group of Brazilian bean genotypes showed a large behavioral variation in terms of resistance to *A. obtectus*. Thus, the most promising genotypes should be used in breeding programs to obtain common bean lines resistant to *A. obtectus*, a bruchid pest species of importance worldwide. In addition, these genotypes should preferably be cultivated by small farmers in regions where this pest species is considered the most important in the post-harvest period.

Our results demonstrate that the less oviposited genotypes indicate resistance expression of antixenosis in a no-choice test (Baldin et al. 2019). The choice for oviposition sites by pests of stored grains can be influenced by several physical and morphological causes, as reported by Azizoglu (2018), who indicated a negative correlation between tegument hardness and larval penetration. The authors reported that the common bean genotype Akdağ with the highest thickness tegument had the lowest infestation rate by *A. obtectus*. Gbaye and Holloway (2011) stated that seed colors are directly related to colonization of *Callosobruchus maculatus* (F.) (Coleoptera: Chrysomelidae: Bruchinae), while Nazzi et al. (2008) observed that semiochemicals released by *P. vulgaris* seeds directly influenced the host-related behavior of *A. obtectus*.

Host attraction of weevils to dry beans guided by olfactory cues has been reported for a long time (Larson and Fisher 1938). The bean weevil *A. obtectus* exhibits a different fecundity process from other bruchids. The species oviposition peak occurs on the fourth or fifth day after emergence (Parsons and Credland 2003), unlike other species that have their peak oviposition rate on the first or second day after emergence, such as *C. maculatus* and *Callosobruchus chinensis* (L.) (Coleoptera: Chrysomelidae: Bruchinae) (Avidov et al. 1965; Dick and Credland 1984). This may be partially attributed to the requirement of a host stimulant for maximal oogenesis and oviposition in some *A. obtectus* populations.

The considerable number of viable eggs considering the total number of eggs indicated that the larvae penetrated the grain. The percentage means of larval viability were smaller, possibly because of the presence of some compound that plays an antibiotic role, showing that many insects did not reach the adult stage due to the ingestion of some substances (allelochemicals). The analysis of intake per insect and the weight of emerged adults are important parameters to discriminate the types of resistance (Baldin et al. 2019) and should be considered in future tests with promising resistance genotypes to *A. obtectus*.

Some genotypes have a combination of chemical and morphological factors that negatively affect insect behavior or development, hindering the process to isolate causes of antibiosis and antixenosis (Smith and Clement 2012). Therefore, characterization of resistance types in bean genotypes should be subjected to further investigations. However, the smaller number of emerged adults, the decrease of larval viability, and the delayed egg-to-adult developmental time of the genotypes tested may be an indicative of antibiosis resistance (Baldin et al. 2019). These results are possibly related to toxic compounds that delay the development of immature stages of insect pests, such as antibiotics, alkaloids, terpenes, cyanogenic glycosides, and proteins (Gepts 1999, Paes et al. 2000, Sakthivelkumar et al. 2013).

The main proteins associated to bean genotypes resistant to bruchids are lectins, α-amylase inhibitors, proteinase inhibitors, inactivating-protein ribosomes, protein reserves (vicilin) of modified proteins, proteins involved in lipid transport, glucanases, arcelins, and chitinases (Chrispeels and Raikhel 1991, Kasahara et al. 1996, Grossi de Sá and Chrispeels 1997, Franco et al. 1999, Carlini and Grossi de Sá 2002, Baldin and Pereira 2010; Zaugg et al. 2012). These resistance factors can affect nutrient assimilation, delaying insect development or causing its death (Amorim et al. 2008). Thus, further studies should be conducted to assess physical, morphological, and chemical factors associated to resistant bean genotypes.

Studies that mapped common bean resistance genes to weevils found that the expression level of the *Phvul.006G003700* gene in resistant cultivars was much higher compared to genotypes susceptible to bruchids, possibly related to the expression of increased production of α-amylase inhibitors (Li et al. 2022). This enzyme in the saliva and gut of insects and proteinase inhibitors, when linked to digestive enzymes, may be responsible for decreasing insect feeding, producing an anti-insect effect (Boyd et al. 2002). Other authors also confirmed that α-amylase inhibitors are closely related to resistance expression to *A. obtectus* and other bruchids (Basi et al. 1993, Franco et al. 2000, Lüthi et al. 2013).

Arcelin is a protein toxic to several insects, including *A. obtectus* and *Zabrotes subfasciatus* (Mazzonetto and Vendramim 2002, Baldin and Pereira 2010, Baldin et al. 2017, Tigist et al. 2021). Currently, eight variants of arcelin have been identified in wild beans with different resistance levels to bruchids (Osborn et al. 1986, Lioi and Bollini 1989, Cardona et al. 1990, Santino et al. 1991, Acosta-Gallegos et al. 1998, Zaugg et al. 2012). However, some authors proposed that arcelin has little effect on *A. obtectus*, compared to other bruchids (Hartweck et al. 1997, Guzzo et al. 2015). In the present study, Arcelin 1 was associated to genotypes with lower oviposition, smaller number of emerged insects, and consequently smaller means of larval viability (Fig. 1), suggesting the action of the protein in bean resistance to this bruchid (Smith and Clement 2012).

Baldin et al. (2017) used the same method and reported that genotypes Arcelin 1, Arcelin 2, Arcelin 1S, Arcelin 5S, and Arcelin 3S showed antibiosis resistance against *A. obtectus*, corroborating with the results of the present study. Conversely, in the present study genotype Arcelin 3 was grouped with genotypes with the highest oviposition, the largest number of emerged insects, and the highest larval viability (Fig. 1), which could be related to the different resistance levels of arcelin variants or associated to species specific plant resistance to insects (Lara 1991, Smith 2005).

Exposure to plant proteinase inhibitors and α-amylase inhibitors may have negative and positive effects on human physiology and well-being (Clemente et al. 2010, Oliás et al. 2019). Some phytochemicals of legume and cereal, such as α-amylase and α-glucosidase, represent a potential medicine for antidiabetic and overweight treatments due to slower carbohydrate absorption (Payan 2004, Ch'ng et al. 2019). On the other hand, some plant-derived compounds, naturally present in legume and cereal composition, may affect the digestive processes in the human gastrointestinal system and make plant protein less bioaccessible in the human organism (Tomé 2013). Li et al. (2021) reported that proteases inhibitors can be divided into six different classes (knottin-like, Kunitz, thaumatin-like, γ-thionin-like, cereal, and lectin-like). According to these authors, the first three classes affect only amylases of insects and can be therefore used as pest control methods. Therefore, a careful assessment of the antibiotic compounds in these genotypes is needed to ensure food security to many people.

Previous studies have also found resistance of common bean genotypes to other pests (Silva et al. 2014, Santos et al. 2020b, Shaabani et al. 2021, Zimba et al. 2022). No-choice tests with *Bemisia tabaci* (Gennadius) (Hemiptera: Aleyrodidae) Middle East Asia Minor 1 described high levels of antibiosis and/or antixenosis in 'CHIB 06' (Santos et al. 2020a). Thus, this landrace genotype is an interesting option for smallholders due to its resistance levels to this sucking insect (whiteflies), an emerging insect vector of phytopathogens to beans in field conditions, as well as the resistance to the bruchid-pest of stored beans.

CONCLUSION

Studies on resistance characterization of bean genotypes to *A. obtectus* are scarce on literature, with a small number of genotypes tested and consequently restricted genetic variability. This background greatly limits breeding programs, highlighting the importance of the present study, as our findings contribute to improving the existing knowledge. Future studies should be carried out to better characterize the resistance types of promising genotypes to *A. obtectus*, as well as the chemical and morphological factors involved.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

AUTHORS' CONTRIBUTION

Conceptualization: Cabral, I. R., Baldin, E. L. L. and Ribeiro, L. P.; **Investigation:** Cabral, I. R., Faria, R. D., Silva, J. P., Santos, T. L. B., Takaku, V. S. O., Santana, A. S. and Lima, A. P. S.; **Data Curation:** Cabral, I. R., Ribeiro, L. P., and Canassa, V. F.; **Writing – Original Draft:** Cabral, I. R. and Ribeiro, L. P.; **Writing – Review and Editing:** Cabral, I. R. and Ribeiro, L. P.; **Funding Acquisition:** Baldin, E. L. L. and Ribeiro, L. P.; **Supervision:** Baldin, E. L. L.

DATA AVAILABILITY STATEMENT

All dataset were generated and analyzed in the current study.

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