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Population dynamics and infestation of *Holopothrips fulvus* Morgan (Thysanoptera: Phlaeothripidae) in dwarf cashew genotypes

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Abstract: The objective of this study was to evaluate the *Holopothrips fulvus* Morgan (Thysanoptera: Phlaeothripidae) population dynamics and to identify dwarf cashew genotypes less infested by the pest in 2015 and 2016, under field conditions. *H. fulvus* population evaluations were carried out by monthly observations in the plants and using a score scale varying from 0 to 4. *H. fulvus* infestation occurred from October to December, and in the cashew genotypes CAP 112/8, CAP 121/1, CAP 131/2, CAP 145/2, CAP 145/7, CAP 128/2, CAP 120/4, CAP 123/6, CAP 130/1, and CAP 157/2 was dependent on the flowering period of the crop in 2015. In 2016, there was dependence in all evaluated genotypes between *H. fulvus* infestation and the cashew flowering period. In 2015, no significant differences were observed between the evaluated genotypes regarding *H. fulvus* infestation. In 2016, genotypes CAP 105/5, CAP 143/7, CAP 150/3, CAP 155/2, CAP 158/8, CAP 161/7, CAP 163/8, CAP 31, CAP 71, CAP 92, CAP 113, CAP 120, CAP 155, CAP 165, CAP 106/1, CAP 111/2, CAP 127/3, CAP 157/2, and BRS 226 were less infested. *H. fulvus* occurs from October to December and we could identify the dwarf cashew genotypes less infested by the pest.

Key words: *Anacardium occidentale*, population dynamics, resistance of plants, Thysanoptera.

INTRODUCTION

Cashew cultivation in Brazil has high socioeconomic importance, especially in the states that are located in the semi-arid regions of the northeast (Serrano & Oliveira 2013). In the 2017 harvest, the production of cashew nuts, the main product of the crop, reached 134,000 tonnes, and the States of Ceará, Piauí, and Rio Grande do Norte accounted for 89.5% of this production (IBGE 2018). However, this production has been affected by several insect pests, which interfere with the yield and the quality of the fruits, resulting in low economic return (Serrano & Oliveira 2013).

In Brazil, *Holopothrips fulvus* Morgan (Thysanoptera: Phlaeothripidae) was recently reported damaging dwarf cashews in the municipality of Pacajus, Ceará (Lima et al. 2017). This species of thrips feeds on cashew leaves and fruits, which can damage the reproductive organs (flowers), producing necrotic spots in the feeding site, around the insertion point of the nut, in the accessory fruit, and in the abaxial surface of the leaf, which become yellow and wilted, causing the senescence and fall of leaves and inflorescences (Lima et al. 2017). Thrips can cause direct damages from the sucking of the sap and consequent reduction in the photosynthetic rate of plants. They also cause abortion of flowers and reduction of fruiting from the consumption of pollen grain (Riley et al. 2011b). Indirect damages can occur with the transmission of phytopathogens, especially tospovirus (Rotenberg et al. 2015).

In Brazil, cashew producers do not have certified formulated products or active ingredients to control *H. fulvus*, probably because of their recent introduction to the country, however, studies aimed at the management of this pest are necessary since thrip population outbreaks in other agricultural crops may cause significant losses in production (Pereira et al. 2017, Kaur et al. 2018). In fact, chemical control appears to be the most widely used method for thrip management. However, the indiscriminate use of synthetic chemical molecules has increased the selection pressure, favoring the emergence of resistant populations, as well as the death of natural enemies and contamination of the environment and animals (Wang et al. 2016, Conte et al. 2014, Ferreira et al. 2017).

In this way, the knowledge and use of other control tactics within Integrated Pest Management (IPM) are of the utmost importance. Plant resistance to insects is an effective alternative, within the IPM context, as it offers a long-lasting solution with minimal financial investment for the maintenance of phytophagous insect populations. In addition, the knowledge about the dynamics of thrips in agricultural crops seems to be a key point in their management, since their populations may occur at different times of the year from the influence of abiotic factors (Lin et al. 2015, Ahmed et al. 2017).

In Brazil, studies on the *H. fulvus* resistance of cashew genotypes and the knowledge about their population dynamics in this crop have been neglected. Therefore, the objective of this work was to (1) evaluate the *H. fulvus* population dynamics in dwarf cashew genotypes and (2) to identify dwarf cashew genotypes less infested by *H. fulvus* under field conditions during the crop years 2015/2016.

MATERIALS AND METHODS

The study was conducted in an experimental plantation of dwarf cashew plants (Campo Experimental da Embrapa Agroindústria Tropical) aged approximately 5 years, in Pacajus, State of Ceará, Brazil (4°11’ S, 38°29’ W) from Jan. 2015 to Dec. 2016. The experimental area had 35 genotypes (Table I), distributed in blocks of 35 plants, each plant cultivated with 8.0 m between rows and 6.0 m between plants. According to Köppen climate classification (Kottek et al. 2006), the local climate is the equatorial savanna with dry winter, which is a climatically arid region with rainy season concentrated between February and March. Environmental data (rainfall and temperature) were registered at a weather station located 3.4 km from the experimental area. During the experiment, no phytosanitary practices were carried out.

H. fulvus population dynamics in cashew plants

We considered all genotypes to evaluate the *H. fulvus* population dynamics in cashew plants. The *H. fulvus* population dynamics was evaluated indirectly through leaf damage, estimated by a diagrammatic scale (Figure 1). According to the scale, 0 corresponds to a healthy leaf, 1 corresponds to 1-25% of leaf area damaged, 2 corresponds to 26-50% of leaf area damaged, 3 corresponds to 51-75% of leaf area damaged, and 4 corresponds to >75% of leaf area damaged and change in color (yellowing).

For two years (2015-2016), at monthly intervals, ten leaves were randomly collected from eight plants of each genotype (2800 leaves per month). The mean level of damage was obtained from the mean scores of the leaves and plotted as a function of time. Since the damage of *H. fulvus* was not observed throughout the year, we performed an association test between the occurrence of damage and the flowering period using a presence-absence matrix (contingency table, according to Ludwig & Reynolds 1988). The association was quantified by Pearson's chi-squared test:

$$\frac{N(ad)-(bc)-(\frac{N^2}{2})}{(a+b)(c+d)(a+c)(b+d)}$$

In this equation, *a* corresponds to the time intervals when both damage and the flowering period occurred in the field, *b* corresponds to only when damage occurred, *c* corresponds to only when the flowering period occurred, *d* corresponds to when neither damage nor the flowering period occurred, and *N* corresponds to all time intervals (96 = eight plants x 12 months). According to the association test, the variables

Table I. Dwarf cashew genotypes evaluated in the Experimental Field of Pacajus, State of Ceará, Brazil, 2015-2016.

Genotypes			
CAP 105/5	CAP 155/2	CAP 120	CAP 115/5
CAP 111/3	CAP 158/8	CAP 155	CAP 120/4
CAP 112/8	CAP 161/7	CAP 165	CAP 123/6
CAP 121/1	CAP 163/8	CAP 170	CAP 130/1
CAP 131/2	CAP 31	CAP 106/1	CAP 157/2
CAP 143/7	CAP 51	CAP 111/2	PRO 805/4
CAP 145/2	CAP 71	CAP 120/2	CCP 76
CAP 145/7	CAP 92	CAP 128/2	BRS 226
CAP 150/3	CAP 113	CAP 127/3	-

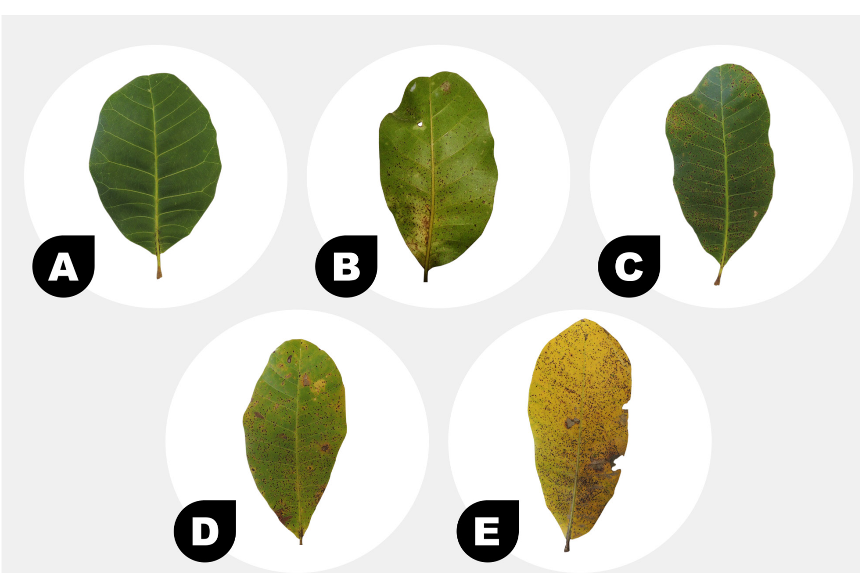

Figure 1. Damage in cashew leaves after *H. fulvus* attack, a) healthy leaf (Score 0), b) leaf with 25% of attack symptoms (Score 1), c) leaf with 50% of attack symptoms (Score 2), d) leaf with 75% of attack symptoms (Score 3), e) leaf with 100% of attack symptoms and yellowing (Score 4).

are dependent when χ^2 is significant ($P < 0.05$), while they are independent when it is not significant ($P > 0.05$).

H. fulvus infestation in different cashew genotypes

To evaluate the susceptibility of the different cashew genotypes, mean damage levels were subjected to the generalized linear model (SAS Institute 2001), in which genotype, year, and month were the independent variables. Subsequently, the means were compared by Fisher's exact test or Tukey's HSD test.

RESULTS

Holopothrips fulvus infestations occurred from October to December, corresponding to the flowering months of the cashew crop, in the crop years 2015 and 2016. In the months of occurrence, a peak was observed in November in the mean damage score, decreasing in December (Figure 2).

In 2015, *H. fulvus* infestation in genotypes CAP 112/8, CAP 121/1, CAP 131/2, CAP 145/2, CAP 145/7, CAP 128/2, CAP 120/4, CAP 123/6, CAP 130/1, and CAP 157/2 was dependent on the flowering period of the crop (Table II). In 2016, there was dependence in all evaluated genotypes between *H. fulvus* infestation and the cashew flowering period (Table II).

There was an interaction between genotypes and evaluation years. In 2015, no significant differences were observed between the evaluated genotypes regarding *H. fulvus* infestation. In this same year, genotypes CAP 150/3, CAP 155/2, CAP 161/7, CAP 163/8, CAP 31, CAP 51, CAP 71, CAP 113, CAP 120, CAP 165, CAP 170, CAP 106/1, CAP 111/2, and BRS 226 were not infested by the insect (Table III).

In 2016, all genotypes were infested, and genotypes CAP 115/5, CAP 131/2, and CAP 120/4 were considered the most infested, while genotypes CAP 105/5, CAP 143/7, CAP 150/3, CAP 155/2, CAP 158/8, CAP 161/7, CAP 163/8, CAP 31, CAP 71, CAP 92, CAP 113, CAP 120, CAP 155, CAP 165, CAP 106/1, CAP 111/2, CAP 127/3, CAP 157/2, and BRS 226 were the least infested. Genotypes CAP 111/3, CAP 112/8, CAP 121/1, CAP 145/2, CAP 145/7, CAP 51, CAP 170, CAP 120/2, CAP 128/2, CAP 123/6, CAP 130/1, PRO 805/4, and CCP 76 had intermediate infestations (Table III).

Genotypes CAP 131/2, CAP 115/5, CAP 120/4, CAP 130/1, PRO 805/4, and CCP 76 had greater

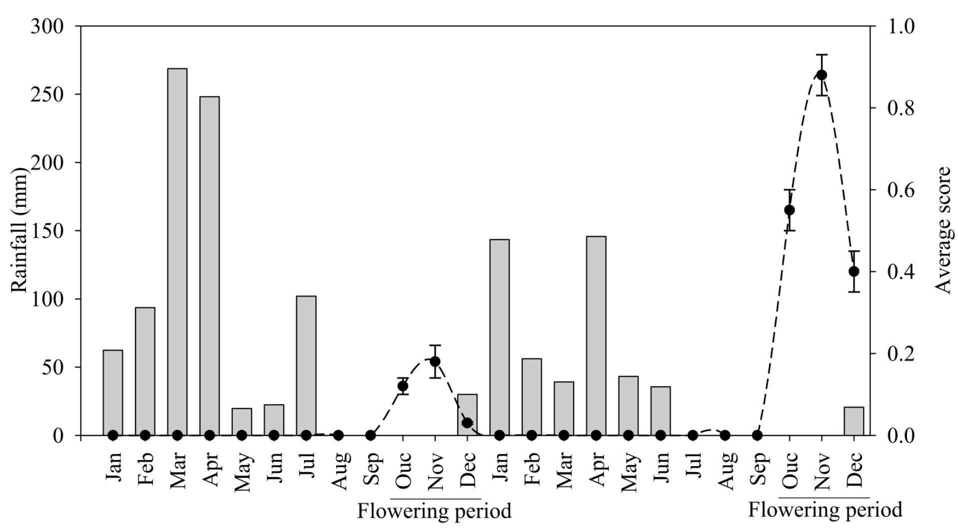

Figure 2. Average score (and corresponding standard errors) of *A. occidentale* leaves infested by *H. fulvus*, as well as monthly rainfall (mm), between January 2015 and December 2016. Flowering period corresponds to the inflorescence and fruit-ripening.

Table II. Association between *H. fulvus* and the flowering period of *A. occidentale*. [1]P < 0.05 = There was an association in the same sample interval (i.e., they were dependent), P > 0.05 = The species occurred in a different time interval (i.e., they were independent), *there was no occurrence of *H. fulvus*.

Genotype	2015			2016		
	χ^2	Df	P[1]	χ^2	df	P
CAP 105/5	3.03	1	0.0817	22.65	1	<0.0001
CAP 111/3	3.03	1	0.0817	26.18	1	<0.0001
CAP 112/8	6.13	1	0.0133	33.49	1	<0.0001
CAP 121/1	12.52	1	0.0004	26.18	1	<0.0001
CAP 131/2	9.29	1	0.0023	66.46	1	<0.0001
CAP 143/7	3.03	1	0.0817	15.82	1	<0.0001
CAP 145/2	22.65	1	<0.0001	53.33	1	<0.0001
CAP 145/7	19.20	1	<0.0001	57.60	1	<0.0001
CAP 150/3	-*	-	-	6.13	1	0.0133
CAP 155/2	-	-	-	19.20	1	<0.0001
CAP 158/8	3.03	1	0.0817	19.20	1	<0.0001
CAP 161/7	-	-	-	15.82	1	<0.0001
CAP 163/8	-	-	-	9.29	1	0.0023
CAP 31	-	-	-	15.82	1	<0.0001
CAP 51	-	-	-	29.79	1	<0.0001
CAP 71	-	-	-	9.29	1	0.0023
CAP 92	3.03	1	0.0817	15.82	1	<0.0001
CAP 113	-	-	-	3.03	1	0.0817
CAP 120	-	-	-	15.82	1	<0.0001
CAP 155	3.03	1	0.0817	9.29	1	0.0023
CAP 165	-	-	-	12.52	1	0.0004
CAP 170	-	-	-	29.79	1	<0.0001
CAP 106/1	-	-	-	12.52	1	0.0004
CAP 111/2	-	-	-	19.20	1	<0.0001
CAP 120/2	3.03	1	0.0817	33.49	1	<0.0001
CAP 128/2	15.82	1	<0.0001	53.33	1	<0.0001
CAP 127/3	3.03	1	0.0817	12.52	1	0.0004
CAP 115/5	3.03	1	0.0817	33.49	1	<0.0001
CAP 120/4	12.52	1	0.0004	49.17	1	<0.0001
CAP 123/6	9.29	1	0.0023	41.14	1	<0.0001
CAP 130/1	6.13	1	0.0133	41.14	1	<0.0001
CAP 157/2	6.13	1	0.0133	9.29	1	0.0023
PRO 805/4	3.03	1	0.0817	49.17	1	<0.0001
CCP 76	3.03	1	0.0817	49.17	1	<0.0001
BRS 226	-	-	-	6.13	1	0.0133

Table III. Mean scores of *H. fulvus* infestation in crop years 2015/2016. Means followed by the same uppercase letter in the column and lowercase letter in the row do not differ statistically from each other by Tukey test (P < 0.05), *letters only where there is statistical difference.

	2015				2016			
Treatment	**October**	**November**	**December**	**Mean**	**October**	**November**	**December**	**Mean**
CAP 105/5	0±0	0.38±0.13	0±0	0.125±0.03*	0.25±0.10	1.00±0.13	0.25±0.10	0.500±0.04 B
CAP 111/3	0±0	0.38±0.13	0±0	0.125±0.03	0.50±0.12	0.63±0.12	0.63±0.12	0.583±0.04 AB
CAP 112/8	0.50±0.15	0.44±0.14	0±0	0.313±0.04	0.63±0.11	0.88±0.13	0.38±0.11	0.625±0.04 AB
CAP 121/1	0.69±0.13	0.63±0.17	0±0	0.438±0.04	1.25±0.16	0.75±0.13	0.25±0.10	0.750±0.05 AB
CAP 131/2	0.38±0.11	0.38±0.13	0±0	0.250±0.04 b	1.00±0.11	1.63±0.12	1.00±0.12	1.208±0.04 Aa
CAP 143/7	0±0	0.25±0.10	0±0	0.083±0.03	0.13±0.07	0.38±0.11	0.25±0.08	0.250±0.03 B
CAP 145/2	0.44±0.10	0.63±0.11	0±0	0.354±0.03	1.25±0.11	1.13±0.11	0.50±0.11	0.958±0.03 AB
CAP 145/7	0.69±0.13	0.63±0.15	0.13±0.07	0.479±0.04	1.25±0.14	1.00±0.11	1.00±0.13	1.083±0.04 AB
CAP 150/3	-	-	-	-	0.13±0.07	0.13±0.07	0±0	0.083±0.02 B
CAP 155/2	-	-	-	-	0.75±0.13	0.50±0.12	0.25±0.10	0.500±0.04 B
CAP 158/8	0.13±0.07	0±0	0±0	0.042±0.02	0.63±0.12	0.63±0.13	0±0	0.417±0.04 B
CAP 161/7	-	-	-	-	0.50±0.15	1.00±0.14	0±0	0.500±0.04 B
CAP 163/8	-	-	-	-	0.25±0.08	0.13±0.07	0±0	0.125±0.02 B
CAP 31	-	-	-	-	0.50±0.12	0.25±0.08	0.25±0.10	0.333±0.03 B
CAP 51	-	-	-	-	0.50±0.13	0.75±0.12	0.63±0.12	0.625±0.04 AB
CAP 71	-	-	-	-	0±0	0.63±0.14	0.25±0.10	0.292±0.04 B
CAP 92	0.13±0.07	0±0	0±0	0.042±0.02	0.25±0.10	0.38±0.11	0.38±0.11	0.333±0.03 B
CAP 113	-	-	-	-	0±0	0.25±0.11	0±0	0.083±0.03 B
CAP 120	-	-	-	-	0.13±0.07	0.25±0.08	0.38±0.11	0.250±0.03 B
CAP 155	0±0	0.13±0.07	0±0	0.042±0.02	0±0	0.50±0.12	0.25±0.10	0.250±0.03 B
CAP 165	-	-	-	-	0.25±0.08	0.25±0.10	0.13±0.07	0.208±0.03 B
CAP 170	-	-	-	-	0.25±0.08	0.88±0.11	0.63±0.14	0.583±0.04 AB
CAP 106/1	-	--	-	-	0.13±0.07	0.25±0.08	0.25±0.10	0.208±0.03 B
CAP 111/2	-	-	-	-	0.13±0.07	0.38±0.09	0.25±0.08	0.250±0.03 B
CAP 120/2	0±0	0.13±0.07	0±0	0.042±0.02	0.38±0.11	1.13±0.12	0.50±0.11	0.667±0.04 AB
CAP 128/2	0.13±0.07	0.75±0.13	0±0	0.292±0.03	1.38±0.11	1.50±0.13	0.38±0.13	1.083±0.04 AB
CAP 127/3	0.13±0.07	0±0	0±0	0.042±0.02	0.13±0.07	0.38±0.11	0.13±0.07	0.208±0.03 B
CAP 115/5	0.13±0.07	0±0	0±0	0.042±0.02 b	1.13±0.16	1.38±0.16	1.00±0.17	1.167±0.05 Aa
CAP 120/4	0.38±0.10	0.25±0.08	0±0	0.208±0.03 b	1.50±0.13	1.50±0.16	0.75±0.13	1.250±0.05 Aa
CAP 123/6	0±0	0.50±0.11	0±0	0.167±0.03	0.75±0.10	1.13±0.11	0.25±0.10	0.708±0.04 AB
CAP 130/1	0.19±0.09	0.13±0.07	0±0	0.104±0.02 b	1.25±0.13	1.00±0.12	0.63±0.15	0.958±0.04 ABa
CAP 157/2	0.19±0.09	0.25±0.10	0±0	0.146±0.03	0.13±0.07	0.25±0.10	0.38±0.13	0.250±0.04 B
PRO 805/4	0.13±0.07	0±0	0±0	0.042±0.02 b	0.75±0.10	1.50±0.13	0.63±0.12	0.958±0.04 ABa
CCP 76	0±0	0.50±0.15	0±0	0.167±0.04 b	1.25±0.13	1.38±0.14	0.63±0.13	1.083±0.04 ABa
BRS 226	-	-	-	-	0±0	0.38±0.11	0±0	0.125±0.03 B

infestations in 2016 compared to 2015. The other genotypes did not differ between the evaluation years (Table III).

DISCUSSION

The occurrence of *H. fulvus* did not vary throughout the evaluation year in the study area. Population peaks were observed in the driest months of the year, corresponding to the phenological stage of flowering of the cashew crop. For 2016, regardless of the cashew genotype, there was dependence between *H. fulvus* infestations and the flowering stage. The presence of *H. fulvus* in cashew flowers and fruits is known (Lima et al. 2017) and the largest populations of these insects in the flowering months may be related to their preference for these plant organs. Population outbreaks of *Selenothrips rubrocinctus* (Giard), *Scirtothrips dorsalis* Hood, and *Azaleothrips* sp. are common at the time of flowering of the cashew crop (Bigger 1960, Navik et al. 2016). The pollen grains present in the cashew panicles may partially explain the dependence of the occurrence of *H. fulvus* on the flowering period. Pollen is an important alternative nutritional factor for the development and reproduction of the floral thrips *Frankliniella occidentalis* (Pergande) in the cotton crop (Trichilo & Leigh 1988), and it is responsible for increasing the populations of *Frankliniella fusca* (Hinds) and other species of thrips in *Nicotiana tabacum* (tobacco) (Riley et al. 2011a).

It is also believed that the occurrence of *H. fulvus* from October to December, in the cashew crop, is also related to the low rainfall in this period, considered the dry season with high temperatures, being thus the most favorable period for the biological development of the pest (Morsello et al. 2008, Reitz 2009). Similarly, significant negative correlations have been found between rainfall and the populations of *Scirtothripes dorsalis* and *Azaleothrips* sp. in cashew panicles (Navik et al. 2016).

The behavior of increased *H. fulvus* populations in October, in the flowering and fruiting period of the cashew crop, and decreased populations in December, when the fruit is harvested, corroborates the studies of Palomo et al. (2015), who have found higher *Frankliniella occidentalis* population densities during tomatillo flowering, and a decrease in this density during its fruiting stage. *H. fulvus* infestation during this period gives the pest a great potential to damage the crop, since it can damage an important stage, that is the production.

Holopothrips fulvus abundance was highly seasonal, occurring at the same time in the two years of study, with an increase in infestation from one year to the next, this increase may be related to the establishment of the insect in the field, as the cashew crop is perennial. In contrast, in annual short cycle crops, such as onion and cabbage, the seasonality of the *Thrips tabaci* Lindeman species may vary (Nault et al. 2014).

Different patterns of *H. fulvus* infestation in cashew genotypes in 2016 may be related to lower insect preference for certain plants as hosts, justifying the low infestations in genotypes CAP 105/5, CAP 143/7, CAP 150/3, CAP 155/2, CAP 158/8, CAP 161/7, CAP 163/8, CAP 31, CAP 71, CAP 92, CAP 113, CAP 120, CAP 155, CAP 165, CAP 106/1, CAP 111/2, CAP 127/3, CAP 157/2, and BRS 226 .

Similarly, cashew genotype BRS 226 was considered one of the least preferred by *Crimissa cruralis* Stal (Coleoptera: Crisomelidae) under field conditions (Dias-Pini et al. 2018). In other studies, clone CAP 143/7 stood out as the least preferred, in this case for the whitefly *Aleurodicus cocois* (Curtis) (Hemiptera: Aleyrodidae), under controlled conditions, as it has a high number of glandular trichomes, a greater number of cuticular streaks, and higher amounts of phenolic compounds (Goiana et al. 2019).

In fact, in thrips, the attraction of adult insects may vary according to genotype (Zhang et al. 2014, Tu et al. 2016, Badenes-Pérez & López-Pérez 2018), chemical and physical plant resistance mechanisms may be involved. Among the chemical characteristics, the presence of acylsugars in tomato plants (Mirnezhad et al. 2010), high amounts of flavonoid (deuteolin), phenylpropanoid (synapic acid), and amino acid (b-alanine) in carrot leaves (Leiss et al. 2013), higher levels of phenylpropanoids (chlorogenic acid and feruloyl quinic acid) in chrysanthemum (Leiss et al. 2009b), and pyrrolizidine alkaloids in *Senecio* (Leiss et al. 2009a) may confer resistance against thrips. For morphological traits, rapid growth, greater density of trichomes (Kaur et al. 2018), and absence of glandular cells (Zhang et al. 2014) in cotton plants and the presence of glandular trichomes in other plants are related to less damage by thrips (Scott Brown & Simmonds 2006).

Therefore, given the lack of more information in the literature on *H. fulvus* in the cashew crop, our results provide unprecedented evidence for the occurrence of *H. fulvus* associations between the different dwarf cashew genetic materials, as well as their seasonal variation. However, it would be interesting to investigate the causes of resistance of the less infested clones, so that the materials could be considered as candidates for further investigation within our genetic improvement program, whose main objective is to increase the cashew resistance to biotic stress.

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