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Common bean resistance expression to whitefly in winter and rainy seasons in Brazil

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ABSTRACT: Whitefly *Bemisia tabaci* (Gennadius) biotype B is the major pest of common bean (*Phaseolus vulgaris* L.) in Brazil and other countries. Host plant resistance is one of the cornerstones of Integrated Pest Management (IPM), and assessment of cultivars for insect resistance is fundamental to provide farmers options for pest control. This study evaluated common bean resistance to whitefly in the winter and rainy seasons in Jaboticabal, Brazil, and correlated the infestation with climatic factors. The plant part and development period of common bean that are more susceptible to whitefly infestation were also examined for potential use in IPM. Field experiments were carried out using 18 and 19 commercial cultivars in the winter and rainy seasons, respectively. Whitefly eggs, nymphs, and adults in the upper part and lower part of plants were sampled from 25 to 60 days after emergence (DAE). Cultivars IAC-Una and IAC-Eldorado had less oviposition and the former also showed lower adult infestation in the winter season. In the rainy season, cultivars IAPAR-81 and Guará had a smaller number of eggs, whereas IAC-Centauro was less infested by nymphs. The number of nymphs and adults was similar among cultivars in the winter and rainy seasons, respectively. The upper part of plants had a greater number of eggs and adults, while, the lower part harbored larger numbers of nymphs. Common bean was more susceptible to whitefly at 25-32 DAE in both seasons. These results add useful information to IPM of whitefly in common bean.

Keywords: *Phaseolus vulgaris*, *Bemisia tabaci*, Aleyrodidae, host plant resistance, integrated pest management

Introduction

Whitefly *Bemisia tabaci* (Gennadius) biotype B (Hemiptera: Aleyrodidae) is the major pest of common bean (*Phaseolus vulgaris* L.) in Brazil and other countries that cultivate the crop (Morales, 2001). Nymphs and adults cause direct damage by removing phloem nutrients and inoculating salivary toxic enzymes, which weakens plants and reduces grain yield and quality (Inbar and Gerling, 2008). Indirect damage arises from sooty mold proliferation on whitefly excrements deposited on leaves and flowers, impairing plant respiration and photosynthesis (Oliveira et al., 2001). The whitefly also transmits the golden bean mosaic virus, a major threat to common bean in Latin America (Morales and Anderson, 2001).

Host plant resistance is characterized by the use of cultivars that have chemical, physical, and/or morphological mechanisms acting alone or in combination to reduce insect infestation by affecting herbivore preference (antixenosis) and performance (antibiosis) or by keeping or promoting plant fitness after herbivory (tolerance) (Mitchell et al., 2016). Some common bean cultivars have shown levels of resistance to *B. tabaci* biotype B through antixenosis and/or antibiosis (Jesus et al., 2010; Silva et al., 2014). Thus, assessment of novel cultivars for whitefly resistance traits is fundamental to provide farmers options of pest control.

Environmental factors play an important role on population dynamics of insect pests. Although there are various reports on the influence of environmental factors on whitefly infestation (Seif, 1981; Leite et al., 2005; Xiao et al., 2016; Jha and Kumar, 2017; Kataria et al., 2017), few studies evaluated infestations on a range of plant cultivars (Umar et al., 2003; Zia et al., 2013; Zeshan et al., 2015). Thus, understanding the effects of abiotic factors on whitefly population dynamics in different cultivars could provide insights into which cultivar is recommended for planting in specific seasons.

For an effective IPM, it is important to know the plant part preferred for pest feeding/oviposition and periods of plant development with the highest pest infestations. In this sense, efforts should focus on specific plant sites and growth stages to monitor pests and use control methods effectively. This study evaluated resistance of common bean cultivars to *B. tabaci* biotype B, plant part preferred by insects, infestation levels across plant development in the winter and rainy seasons in Brazil, and correlated whitefly infestation with climatic factors in these seasons.

Materials and Methods

Experimental site conditions

Two experiments were conducted in an experimental field during 2010-2011 in Jaboticabal, state of São Paulo, Brazil (21°15′22″ S; 48°15′58″ W; 595 m altitude). The climate in the region is classified as tropical savanna (Aw) (Alvares et al., 2013) and the soil type as rhodic hapludox (Soil Survey Staff, 1999) (red latosol, according to Embrapa, 2006).

Common bean cultivars and sowing conditions

Resistance was evaluated in 18 common bean cultivars that are currently used by Brazilian growers and available in the marketplace: IAC-Formoso, IAC-Diplomata, IAC-Una, IAC-Alvorada, IAC-Harmonia, IAC-Galante, IAC-Carioca-Eté, IAC-Centauro, IAC-Carioca-Tybatã, BRS-Supremo, BRS-Requinte, BRS-Pontal, BRS-Cometa, IAPAR-81, IPR-Siriri, IPR-Eldorado, Guará, and IPR-139. These cultivars were compared with cultivar Pérola, chosen as the standard cultivar because it is one of the most planted by farmers in Brazil. In addition, cultivar Pérola is susceptible to whitefly (Silva et al., 2014). For the winter season experiment, cultivar IAC-Harmonia was not evaluated beacause an insufficient number of plants emerged and it was therefore removed from analysis of that season.

Seeds were sown on 6 July 2010 in the winter season and on 7 Dec 2010 in the rainy season. Seeds were treated with fungicide (tetramethylthiuram disulfide) at recommended dosage (MAPA, 2003) prior to sowing. Seeds were sown at 0.5 m spacing between rows, 15 seeds per row meter. Each experimental plot consisted of four rows 4 m long, totalizing an area of 8 m^2. We placed 18 cultivars in the winter season and 19 cultivars in the rainy season in plots randomly arranged in blocks, and fours blocks were used as replicates. Upon sowing, soil was fertilized with NPK (04-14-08) at 430 kg ha^{-1}, and topdressing fertilization (180 kg ha^{-1}) was applied 20 days after emergence (DAE). Plants were thinned to 12 plants per row meter 10 DAE. Weeds were manually removed and no insecticides were applied in the experimental field in both seasons. Natural infestation of whiteflies was evaluated in the experiment.

Whitefly sampling

B. tabaci biotype B was sampled weekly, commencing 25 DAE and ending 60 DAE, totaling six samplings per season. Numbers of whiteflies were recorded in 10 leaflets randomly taken from the upper part and 10 leaflets from the lower part of plants in two central rows of the plots. To standardize evaluation, samplings initiated in the morning (between 08h30 a.m. and 09h30 a.m.) and only one leaflet was taken per plant. To sample eggs and nymphs, leaflets were detached from plants, stored in labeled paper bags, and taken to the laboratory where the numbers of insects were recorded under a stereomicroscope (40x magnification). Adults were inspected on undetached leaves using the leaf-turn method (Naranjo and Flint, 1995).

Statistical analysis

The experiments were conducted in randomized block design with split-split plot arrangement. In the winter season, the experimental design consisted of 18 cultivars by 2 leaf positions by 6 sampling dates, and for the rainy season the design consisted of 19 cultivars by 2 leaf positions by 6 sampling dates, with four replicates. Data on insect numbers were checked for normality of residuals and homogeneity of variances, and required squareroot (x + 0.5) transformation to meet the assumptions of analysis of variance (ANOVA). Transformed data were analyzed by ANOVA with cultivars assigned as the main plots, leaf positions as the split-plots, and sampling dates as the split-split plots. Treatment means were separated by the Tukey HSD test ($\alpha = 0.05$), when difference was significant. Data on winter and rainy seasons were analyzed separately.

Data on climatic variables were recorded and averaged for weeks of whitefly sampling dates (Table 1). Climatic data were obtained by an agrometereological station located near the experimental field. Infestations of whitefly eggs, nymphs, and adults in each season were correlated (the Pearson linear correlation analysis) with the climatic factors minimum temperature, average temperature, maximum temperature (°C), minimum relative humidity, av-

Table 1 – Mean values of temperature, relative humidity and rainfall registered in the weeks of sampling of *Bemisia tabaci* biotype B on common bean cultivars in the winter and rainy seasons in Jaboticabal, Brazil.

Sampling dates (DAE)	Temperature			Relative humidity			Rainfall
	Minimum	Average	Maximum	Minimum	Average	Maximum	
	°C			%			mm
			Winter season				
25	14.6	21.7	29.8	23.9	50.3	77.6	0
32	11.5	19.4	28.5	23.7	54.2	83.9	0
39	11.6	18.7	26.9	22.7	50.1	78.5	0
46	12.2	20.9	29.9	14.5	34.2	63.8	0
53	15.9	24.4	33.2	14.5	33.0	56.5	0
60	16.1	23.2	31.0	26.8	48.2	70.6	7.7
			Rainy season				
25	20.4	23.5	29.6	52.9	82.8	94.9	49.7
32	20.7	23.6	29.1	58.3	84.7	94.5	101.5
39	20.6	25.0	31.3	50.8	76.2	92.6	0.7
46	20.6	25.8	32.7	37.8	68.1	90.1	7.0
53	19.9	24.1	31.9	44.6	76.6	93.3	74.9
60	20.3	24.7	31.5	43.8	74.0	92.4	4.9

DAE = days after emergence.

erage relative humidity, maximum relative humidity (%), and rainfall (mm). The statistical analysis was performed using the GLM procedure in SAS (SAS Institute, 2004).

Results

Winter season experiment

No differences were observed for cultivar (C) × leaf position (L) and cultivar × sampling date (D) interactions on infestations of eggs (C × L: $F_{17, 54} = 0.35$; $p = 0.9930$; C × D: $F_{85, 540} = 0.44$; $p = 1$), nymphs (C × L: $F_{17, 54} = 0.29$; $p = 0.9981$; C × D: $F_{85, 540} = 0.64$; $p = 0.9941$), and adults (C × L: $F_{17, 54} = 1.01$; $p = 0.4448$; C × D: $F_{85, 540} = 1.16$; $p = 0.1666$) of *B. tabaci* biotype B. Differences for cultivar × leaf position × sampling date interaction were not observed for the numbers of eggs ($F_{85, 540} = 0.55$; $p = 0.9995$), nymphs ($F_{85, 540} = 0.61$; $p = 0.9970$), and adults ($F_{85, 540} = 1.13$; $p = 0.2176$).

Differences were observed for infestations of eggs ($F_{17, 51} = 2.21$, $p = 0.0150$) and adults ($F_{17, 51} = 2.60$, $p = 0.0044$) among 18 cultivars tested in the winter season (Table 2). All cultivars were equally infested by nymphs ($F_{17, 51} = 0.65$, $p = 0.8318$). Cultivars IPR-Eldorado and IAC-Una showed a smaller number of eggs than BRS-Supremo and IAC-Galante, which were the most preferred cultivars for oviposition. Whitefly adult infestation was lower in cultivar IAC-Una, similar to egg infestation. The number of adults in IAC-Una was different from that of Pérola and IAC-Centauro, which had higher infestation.

The effects of leaf position interacted with the effects of sampling dates for infestations of eggs ($F_{5, 540} = 7.75$; $p < 0.0001$) and nymphs ($F_{5, 540} = 7.86$; $p < 0.0001$) (Table 3), but not of adults ($F_{5, 540} = 1.57$; $p = 0.1660$); therefore, data on adults were not presented in Table 3.

Table 2 – Mean numbers (± SE) of eggs, nymphs, and adults of *Bemisia tabaci* biotype B in 18 cultivars of common bean in the winter season.

Cultivars	Eggs	Nymphs	Adults
IPR-Eldorado	1.33 ± 0.28 b	0.34 ± 0.21 a	0.77 ± 0.13 ab
IAC-Una	1.67 ± 0.42 b	0.20 ± 0.12 a	0.54 ± 0.10 b
IAPAR-81	1.83 ± 0.34 ab	0.34 ± 0.39 a	0.81 ± 0.18 ab
IAC-Formoso	1.96 ± 0.41 ab	0.45 ± 0.40 a	0.89 ± 0.17 ab
BRS-Pontal	2.10 ± 0.40 ab	0.31 ± 0.29 a	0.94 ± 0.16 ab
IPR-139	2.33 ± 0.45 ab	0.49 ± 0.55 a	0.75 ± 0.12 ab
IAC-Diplomata	2.35 ± 0.44 ab	0.40 ± 0.22 a	1.21 ± 0.22 ab
IPR-Siriri	2.44 ± 0.45 ab	0.38 ± 0.26 a	1.31 ± 0.20 ab
IAC-Carioca Eté	2.54 ± 0.60 ab	0.44 ± 0.33 a	0.77 ± 0.14 ab
IAC-Alvorada	2.73 ± 0.54 ab	0.50 ± 0.23 a	0.81 ± 0.17 ab
IAC-Carioca-Tybatã	3.02 ± 0.61 ab	0.31 ± 0.32 a	1.10 ± 0.15 ab
BRS-Requinte	3.12 ± 0.73 ab	0.41 ± 0.36 a	0.71 ± 0.13 ab
Guará	3.21 ± 0.73 ab	0.50 ± 0.62 a	1.06 ± 0.16 ab
Pérola	3.60 ± 0.59 ab	0.30 ± 0.18 a	1.62 ± 0.25 a
IAC-Centauro	3.65 ± 0.69 ab	0.50 ± 0.37 a	1.58 ± 0.26 a
BRS-Cometa	3.81 ± 0.81 ab	0.33 ± 0.17 a	0.96 ± 0.17 ab
IAC-Galante	3.83 ± 0.65 a	0.33 ± 0.26 a	1.10 ± 0.16 ab
BRS-Supremo	4.33 ± 0.69 a	0.33 ± 0.27 a	1.10 ± 0.16 ab

Means followed by different letters in columns are significantly different by the Tukey HSD test ($p < 0.05$).

Egg infestation was higher in the upper part than in the lower part of plants at the three first sampling dates (25, 32, and 39 DAE), with no differences in the remaining evaluations. The upper part of plants had a larger number of eggs at 32 DAE than at 39, 46, and 60 DAE, whereas the lower part of plants showed a smaller number of eggs at all sampling dates, but at 53 DAE. Higher nymph infestation predominated in the lower part of plants (four out of six sampling dates), with greater numbers of nymphs at 32 and 39 DAE. The number of nymphs in the upper part of plants did not differ among sampling dates. Infestations of adults tended to reduce from the first two sampling dates (25 and 32 DAE) to the last one (60 DAE) in both the upper and lower parts of plants, which did dot differ between them.

The effect of leaf position on adult infestation was marginally significant ($F_{1, 57} = 3.56$; $p = 0.0598$), and the number of adults was 13 % higher in the upper part of plants than in the lower part (data not shown). The effect of sampling date on the number of *B. tabaci* adults was highly significant ($F_{5, 540} = 10.21$; $p < 0.0001$). Adult infestation was higher at 25 and 32 DAE, reduced slightly at 39 DAE, and was lower in the three last sampling dates (Figure 1), decreasing to half, compared to the first sampling date.

Rainy season experiment

Infestation of nymphs was influenced by cultivar × leaf position interaction ($F_{18, 57} = 1.74$, $p = 0.0291$), and infestation of adults by cultivar × sampling date interaction ($F_{90, 570} = 1.65$, $p = 0.0004$). No interactive effects were found for cultivar × leaf position on egg ($F_{18, 57} = 0.83$, $p = 0.6651$) and adult infestations ($F_{18, 57} = 0.99$, $p = 0.4669$), and for cultivar × sampling date on egg ($F_{90, 570} = 0.80$, $p = 0.9024$) and nymph ($F_{90, 570} = 0.56$, $p = 0.9995$) infestations. Differences for cultivar × leaf position × sampling date interaction were not observed for the number of eggs ($F_{90, 570} = 0.68$, $p = 0.9882$), nymphs ($F_{90, 570} = 0.61$, $p = 0.9978$), and adults ($F_{90, 570} = 0.97$, $p = 0.5609$).

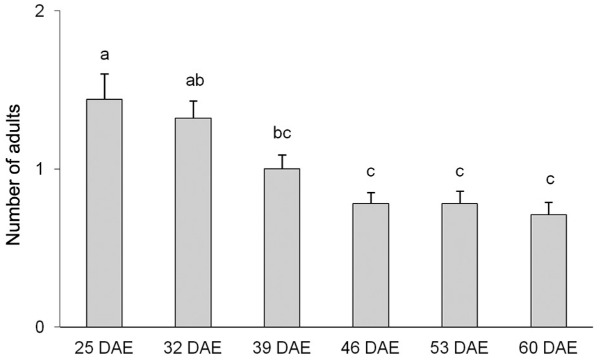

Figure 1 – Mean numbers (± SE) of adults of *Bemisia tabaci* biotype B in 18 cultivars of common bean in six sampling dates in the winter season. Bars topped with different letters are significantly different by the Tukey HSD test ($p < 0.05$).

Infestations of eggs ($F_{5,\ 570}$ = 12.32, p < 0.0001), nymphs ($F_{5,\ 570}$ = 5.77, p < 0.0001), and adults ($F_{5,\ 570}$ = 5.93, p < 0.0001) were affected by leaf position × sampling date interaction during the rainy season (Table 4). Egg infestation was higher in the upper part of plants only at 39 DAE, and did not differ between plant parts in the remaining sampling dates. The number of eggs was higher at 32 and 39 DAE in the upper part of plants and at 25 and 32 DAE in the lower part of plants, and tended to diminish in the subsequent evaluations. Nymph infestation was always higher in the lower part of plants, with differences between plant parts ranging from >100 fold at the beginning of the sampling period to > 4 fold at 53 DAE. In the upper part of plants, the number of nymphs was higher at 46 and 53 DAE and lower at 25 DAE. In the lower part of plants, infestation was higher in the first sampling date and at 53 DAE and lower in the last one (60 DAE). Adult infestation was higher in the upper part of plants in the two first sampling dates (25 and 32 DAE) and remained similiar between leaf positions in the following evaluations. In both plant parts, adult numbers were initially intermediate, increased at 32 DAE, and declined thereafter.

There was difference of egg numbers ($F_{18,\ 54}$ = 1.94, p = 0.0316) between 19 cultivars tested. The number of eggs was lower in IAPAR-81 and Guará, whereas IAC-Harmonia and IPR-Eldorado were preferred for oviposition. The number of eggs was intermediate in the other cultivars (Figure 2).

Nymphs of *B. tabaci* biotype B were more abundant on leaves of the lower part of common bean plants, except for IAC-Centauro, which showed no difference between leaf positions (Table 5). Because of this whitefly behavior, no differences were found for nymph infestation between cultivars in the upper part of plants. In the lower part, cultivar IAC-Centauro was 7.5 orders of magnitude less infested by nymphs than cultivars BRS-Cometa and IPR-Siriri, which had the highest infestation. The other cultivars showed moderate infestation of nymphs.

Infestation of adults on average increased or ramined the same from 25 to 32 DAE and declined until 60 DAE in all cultivars (Table 6). The number of adults differed between cultivars only at 25 and 32 DAE in the rainy season, whereas in the other sampling dates, levels of resistance between cultivars were not detected because of low infestations (Table 6). At 25 DAE, cultivars IPR-Eldorado and IPR-139 showed a small number of adults and differed from Guará, IAC-Carioca-Tybatã, Pérola, IAC-Harmonia, IAC-Una, and BRS-Supremo, which were more infested. At 32 DAE sampling date, cultivars BRS-Supremo, IAC-Una, IAC-Centauro, and IAPAR-81 were less preferred than BRS-Requinte, IAC-Harmonia, IAC-Galante, and IPR-Eldorado.

Correlation between whitefly infestation and climatic variables in the winter and rainy seasons

Infestations of *B. tabaci* biotype B were lower in the winter than in the rainy season. According to Pearson linear coefficient, the winter season showed a marginally significant and positive correlation of nymph infestation × average temperature (r = 0.7965, p = 0.0580). In the rainy season, positive correlations were

Table 3 – Interaction between leaf position and sampling date on the mean numbers (± SE) of eggs and nymphs of *Bemisia tabaci* biotype B in 18 cultivars of common bean in the winter season.

Leaf positions	Sampling dates					
	25 DAE	32 DAE	39 DAE	46 DAE	53 DAE	60 DAE
			Eggs			
Upper	4.00 ± 0.67 aAB	5.53 ± 0.78 aA	2.39 ± 0.30 aC	2.24 ± 0.35 aC	3.87 ± 0.42 aAB	2.42 ± 0.32 aC
Lower	1.19 ± 0.39 bC	1.87 ± 0.44 bC	0.92 ± 0.18 bC	1.65 ± 0.24 aC	4.58 ± 0.55 aA	2.58 ± 0.38 aB
			Nymphs			
Upper	0.22 ± 0.07 aA	0.27 ± 0.07 bA	0.21 ± 0.09 bA	0.14 ± 0.08 bA	0.06 ± 0.02 aA	0.09 ± 0.02 bA
Lower	0.06 ± 0.02 aC	0.95 ± 0.32 aA	1.08 ± 0.36 aA	0.56 ± 0.12 aB	0.30 ± 0.12 aBC	0.62 ± 0.13 aB

Means followed by different lowercase letters in columns and uppercase letters in rows are significantly different by the Tukey HSD test (p < 0.05).

Table 4 – Interaction between leaf position and sampling date on the mean number (± SE) of eggs, nymphs, and adults of *Bemisia tabaci* biotype B in 18 cultivars of common bean in the rainy season.

Leaf positions	Sampling dates					
	25 DAE	32 DAE	39 DAE	46 DAE	53 DAE	60 DAE
			Eggs			
Upper	10.09 ± 0.99 aB	13.95 ± 0.84 aA	14.05 ± 0.45 aA	0.58 ± 0.12 aC	0.63 ± 0.11 aC	0.95 ± 0.19 aC
Lower	8.08 ± 1.68 aA	10.62 ± 1.57 aA	3.72 ± 1.51 bB	0.47 ± 0.10 aC	0.38 ± 0.14 aC	0.71 ± 0.20 aC
	Nymphs					
Upper	0.14 ± 0.09 bB	0.34 ± 0.10 bAB	0.47 ± 0.19 bAB	1.22 ± 0.29 bA	2.95 ± 0.75 bA	0.47 ± 0.12 bAB
Lower	14.74 ± 2.12 aA	8.64 ± 1.40 aB	7.83 ± 0.82 aB	8.13 ± 0.97 aB	12.82 ± 1.31 aA	4.78 ± 0.85 aC
			Adults			
Upper	1.74 ± 0.19 aB	2.50 ± 0.19 aA	0.13 ± 0.04 aC	0.05 ± 0.02 aC	0.01 ± 0.01 aC	0.08 ± 0.03 aC
Lower	1.24 ± 0.18 bB	1.89 ± 0.18 bA	0.29 ± 0.07 aC	0.09 ± 0.04 aC	0.09 ± 0.03 aC	0.10 ± 0.04 aC

Means followed by different lowercase letters in columns and uppercase letters in rows are significantly different by the Tukey HSD test (p < 0.05).

observed for egg infestation × maximum temperature (r = 0.8714, p = 0.0.0240), egg infestation × minimum relative humidity (r = 0.9400, p = 0.0050), egg infestation × average relative humidity (r = 0.8135, p = 0.0490), adult infestation × maximum temperature (r = 0.9388, p = 0.0050), adult infestation × minimum relative humidity (r = 0.8443, p = 0.0340), and adult infestation × average relative humidity (r = 0.8539, p = 0.0300). Correlations between other whitefly infestation data and climatic factors were non-significant (p > 0.05).

Discussion

This study evaluated infestation of whitefly *B. tabaci* biotype B on 18 common bean cultivars in the winter season and on 19 cultivars in the rainy season, in Jaboticabal, Brazil. Because *B. tabaci* biotype B is considered the major insect pest of common bean in Brazil and other Latin American countries (Morales, 2001), this study contributes to whitefly integrated management by providing information on commercial cultivars less suit-

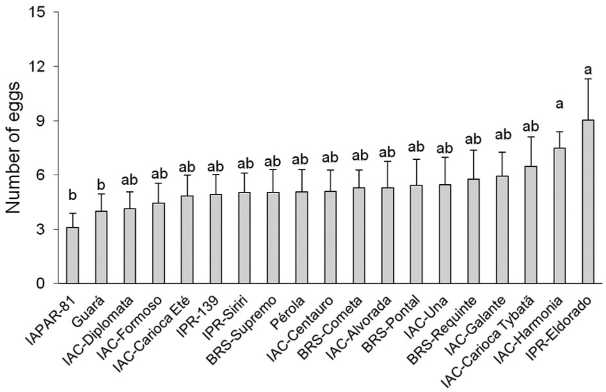

Figure 2 – Mean numbers (± SE) of eggs of *Bemisia tabaci* biotype B in 19 cultivars of common bean in the rainy season. Bars topped with different letters are significantly different by the Tukey HSD test (p < 0.05).

Table 5 – Interaction between common bean cultivar and leaf position on the mean numbers (± SE) of nymphs of *Bemisia tabaci* biotype B in 19 cultivars of common bean in the rainy season.

Cultivars	Leaf positions	
	Upper	Lower
IPR-Eldorado	1.79 ± 0.67 aB	9.83 ± 1.02 bcA
IAC-uma	0.42 ± 0.10 aB	5.96 ± 0.84 bcA
IAPAR-81	0.29 ± 0.08 aB	8.46 ± 1.05 bcA
IAC-Formoso	0.87 ± 0.29 aB	8.29 ± 2.49 bcA
BRS-Pontal	0.37 ± 0.11 aB	9.79 ± 1.11 bcA
IPR-139	0.79 ± 0.23 aB	9.87 ± 1.64 bcA
IAC Diplomata	0.83 ± 0.20 aB	8.37 ± 0.50 bcA
IPR-Siriri	2.21 ± 0.63 aB	16.75 ± 2.44 aA
IAC-Carioca-Eté	0.67 ± 0.15 aB	7.12 ± 0.64 bcA
IAC-Alvorada	0.37 ± 0.12 aB	6.08 ± 0.86 bcA
IAC-Carioca-Tybatã	0.21 ± 0.09 aB	8.58 ± 1.22 bcA
BRS-Requinte	0.50 ± 0.15 aB	7.67 ± 1.12 bcA
Guará	0.92 ± 0.26 aB	14.50 ± 2.24 bA
Pérola	0.92 ± 0.25 aB	10.62 ± 1.24 bA
IAC-Centauro	0.46 ± 0.13 aA	2.21 ± 0.46 dA
BRS-Cometa	0.96 ± 0.30 aB	16.67 ± 2.06 aA
IAC-Galante	0.50 ± 0.15 aB	6.33 ± 1.02 bcA
BRS-Supremo	1.21 ± 0.34 aB	8.83 ± 1.33 bcA
IAC-Harmonia	3.46 ± 0.89 aB	14.33 ± 2.47 bA

Means followed by different lowercase letters in columns and uppercase letters in rows are significantly different by the Tukey HSD test (p < 0.05).

Table 6 – Interaction between common bean cultivar and sampling date on the mean numbers (± SE) of adults of *Bemisia tabaci* biotype B in 19 cultivars of common bean in the rainy season.

Cultivars	Sampling dates					
	25 DAE	32 DAE	39 DAE	46 DAE	53 DAE	60 DAE
IPR-Eldorado	0.25 ± 0.16 cB	3.00 ± 0.62 aA	0.00 ± 0.00 aB	0.12 ± 0.06 aB	0.12 ± 0.06 aB	0.00 ± 0.00 aB
IAC-Una	2.25 ± 0.61 aA	1.37 ± 0.49 bAB	0.62 ± 0.37 aBC	0.25 ± 0.16 aC	0.00 ± 0.00 aC	0.12 ± 0.16 aC
IAPAR-81	1.62 ± 0.46 abA	1.62 ± 0.37 bA	0.12 ± 0.06 aB	0.12 ± 0.06 aB	0.00 ± 0.00 aB	0.00 ± 0.00 aB
IAC-Formoso	1.37 ± 0.70 abB	2.75 ± 0.61 abA	0.37 ± 0.26 aBC	0.25 ± 0.16 aBC	0.00 ± 0.00 aC	0.25 ± 0.16 aBC
BRS-Pontal	0.62 ± 0.26 bcB	2.12 ± 0.51 abA	0.12 ± 0.06 aB	0.00 ± 0.00 aB	0.00 ± 0.00 aB	0.00 ± 0.00 aB
IPR-139	0.50 ± 0.26 cB	2.37 ± 0.37 abA	0.00 ± 0.00 aB	0.00 ± 0.00 aB	0.00 ± 0.00 aB	0.12 ± 0.06 aB
IAC-Diplomata	0.75 ± 0.25 bcB	2.12 ± 0.51 abA	0.12 ± 0.06 aB	0.00 ± 0.00 aB	0.00 ± 0.00 aB	0.12 ± 0.06 aB
IPR-Siriri	1.62 ± 0.46 abAB	2.00 ± 0.42 abA	0.62 ± 0.26 aBC	0.00 ± 0.00 aC	0.12 ± 0.06 aC	0.12 ± 0.06 aC
IAC-Carioca Eté	0.75 ± 0.25 bcB	2.37 ± 0.49 abA	0.12 ± 0.06 aB	0.00 ± 0.00 aB	0.00 ± 0.00 aB	0.00 ± 0.00 aB
IAC-Alvorada	1.00 ± 0.37 bcAB	2.25 ± 0.91 abA	0.12 ± 0.06 aBC	0.00 ± 0.00 aC	0.12 ± 0.06 aBC	0.00 ± 0.00 aC
IAC-Carioca-Tybatã	2.62 ± 0.86 aA	2.50 ± 0.80 abA	0.00 ± 0.00 aB	0.12 ± 0.06 aB	0.12 ± 0.06 aB	0.00 ± 0.00 aB
BRS-Requinte	1.62 ± 0.46 abA	3.00 ± 0.70 aA	0.12 ± 0.06 aB	0.00 ± 0.00 aB	0.12 ± 0.06 aB	0.00 ± 0.00 aB
Guará	2.75 ± 0.37 aA	2.12 ± 0.51 abA	0.37 ± 0.18 aB	0.12 ± 0.06 aB	0.12 ± 0.06 aB	0.50 ± 0.17 aB
Pérola	2.50 ± 0.62 aA	1.75 ± 0.61 abA	0.12 ± 0.06 aB	0.00 ± 0.00 aB	0.00 ± 0.00 aB	0.00 ± 0.00 aB
IAC-Centauro	0.75 ± 0.41 bcAB	1.62 ± 0.41 bA	0.00 ± 0.00 aB	0.00 ± 0.00 aB	0.12 ± 0.06 aB	0.25 ± 0.16 aB
BRS-Cometa	1.50 ± 0.35 abA	1.87 ± 0.54 abA	0.00 ± 0. 00aB	0.00 ± 0.00 aB	0.00 ± 0.00 aB	0.00 ± 0.00 aB
IAC-Galante	1.25 ± 0.45 bcB	2.87 ± 0.47 aA	0.12 ± 0.0.6 aC	0.00 ± 0.00 aC	0.00 ± 0.00 aC	0.25 ± 0.16 aC
BRS-Supremo	2.25 ± 0.49 aA	1.00 ± 0.20 bA	0.12 ± 0.06 aB	0.12 ± 0.06 aB	0.00 ± 0.00 aB	0.00 ± 0.00 aB
IAC-Harmonia	2.25 ± 0.55 aA	2.87 ± 0.83 aA	0.87 ± 0.29 aB	0.25 ± 0.16 aB	0.12 ± 0.06 aB	0.00 ± 0.00 aB

Means followed by different lowercase letters in columns and uppercase letters in rows are significantly different by the Tukey HSD test (p < 0.05).

able to whitefly attack as well as on the plant part and period of development that should be the focus of samplings before undertaking control measures.

Numbers of *B. tabaci* biotype B were lower in the winter than in the rainy season. Abiotic factors play an important role on *B. tabaci* population dynamics and different infestation levels between cropping seasons may be associated with occurrence of climatic conditions unfavorable to whiteflies in the winter season, especially low temperatures. Low temperatures are known to influence negatively whitefly infestation. Optimal conditions for whitelfy development are temperatures between 28 and 33 °C, low relative humidity, and reduced rainfall (Lacasa et al., 1996). This information is consistent with results obtained in our study in that whitefly population densities, mainly eggs and adults, correlated positively with higher temperatures (29.1 to 31.3 °C maximum temperature) and intermediate relative humidity (51 to 58 % minimum relative humidity and 76 to 85 % average relative humidity) in the rainy season.

Studies have reported the effects of abiotic factors on *B. tabaci* population dynamics in various crop species. Keshan et al. (2015) observed that whitefly populations on tomato genotypes were positively correlated with temperature and relative humidity. In contrast, Jha and Kumar (2017) observed that whitefly population densities were negatively correlated with maximum and minimum temperatures. Although in our study the number of whitefly was not correlated with rainfall, Umar et al. (2003) showed that rain influenced whitefly infestation on nectaried and nectariless cotton genotypes, besides temperature and relative humidity. Zia et al. (2013) concluded that *B. tabaci* infestation on transgenic and non-transgenic cotton cultivars correlated positively with temperature and relative humidity and negatively with rainfall. Rainfall influenced negatively *B. tabaci* population densities in at least one cotton cropping season (Kataria et al., 2017). Leite et al. (2005) also documented that whitefly populations in kale were affected negatively by rainfall.

Infestation of *B. tabaci* biotype B differed between common bean cultivars, which also showed variable resistance levels between cropping seasons. In the winter season, cultivars IAC-Una and IAC-Eldorado exhibited a smaller number of eggs than BRS-Supremo and IAC-Galante, and only IAC-Una was less infested by adults than Pérola and IAC-Centauro. In the rainy season, IAPAR-81 and Guará sustained a smaller number of eggs than IPR-Eldorado and IAC-Harmonia, and IAC-Centauro showed the smallest number of nymphs in the lower plant part among all cultivars. Nymph infestation did not differ among cultivars in the winter season. Adult infestation in the rainy season only differed among cultivars in the first sampling dates (25 and 32 DAE), whereby IPR-Eldorado and IPR-139 were less infested than the other cultivars at 25 DAE. IAPAR-81, BRS-Supremo, IAC-Una, and IAC-Centauro were less infested at 32 DAE. On the remaining dates, the low infestation of adults of whitefly did not allow cultivar differentiation. Similar results were observed by Jesus et al. (2010) in Ipameri, state of Goiás, Brazil, where nymph infestation was similar among common bean cultivars and breeding lines, five cultivars from which were used in our study (IAC-Carioca-Tybatã, IAC-Una, Pérola, BRS-Pontal, and BRS-Requinte).

Although climatic factors directly influenced the whitefly infestations, it should not be disregarded the potential indirect effects on infestations through differential expression of resistance of certain cultivars between cropping seasons. Factors intrinsic to insects, plants, and the environment can substantially alter the expression of resistance-related genes in plants (Smith, 2005). Although the influence of insect- and plant-intrinsic factors were more explored regarding expression of resistance, environmental factors received less attention. Daylength, light intensity, temperature, and relative humidity are known to affect expression of plant resistance traits to insect pests (Rogers and Mills, 1974; Johnson et al., 1980; Kennedy et al., 1981; Webster and Starks, 1987; Patterson et al., 1994; Ohm et al., 1997; Snyder et al., 1998; Sharma et al., 2003).

In field conditions, control for variations in environmental factors is not possible. Boiça Júnior et al. (2015b) reported different resistance levels in the same cultivars evaluated against *Caliothrips phaseoli* (Hood) (Thysanoptera: Thripidae) across the winter, rainy, and dry seasons in Brazil. Because of inconsistent correlations between climatic factors and thrips infestation, the authors could not conclude if resistance in cultivars Guará and IAC-Carioca Tybatã was due to variation in temperature or if there were also effects of abiotic factors on resistance expression. Experiments in plant growth chambers with varying environmental conditions, along with the analysis of gene expression, could explain these effects. Information obtained in Boiça Júnior et al. (2015b) and in our study reinforces the need of evaluating and recommending plant cultivars at a regional scale as resistance may not be manifested under given environmental conditions due to gene × environment interaction. Moreover, some cultivars should be recommended for planting in specific seasons in regions where crops are grown year round.

Common bean is cultivated in three cropping seasons throughout the year in Brazil, namely the rainy, dry, and winter seasons. The rainy season corresponds to sowing between Oct and Nov, and harvest between Jan and Feb. The dry season begins in Feb/Mar and common bean is harvested between Apr and July. In the winter season, sowing occurs between Apr and July, and harvest between Aug and Oct (Embrapa, 2010). Our results show that cultivars IAC-Una and IAC-Eldorado could be cultivated in the winter season, and cultivars IAPAR-81, Guará, and IAC-Centauro in the rainy season, as these cultivars were less susceptible to whitefly infestation in the respective seasons. Although high levels of resistance were not found in any of these cultivars, their cultivation in recommended seasons might reduce whitefly populations and economic injury levels, thereby reducing the number of insecticide applications and their associated costs.

Common bean is reported to express resistance through antixenosis and antibiosis (Silva et al., 2014; Boiça Júnior et al., 2015a, b). Information on expression of tolerance to whitefly and other pests is scarce (Frei et al., 2004; Boiça Júnior et al., 2015a). Common bean resistance to *B. tabaci* biotype B is associated to reduced trichome densities on leaves (Oriani and Lara, 2000). Hairs and trichomes act as whitefly oviposition stimulant, and cultivars with higher trichome densities are generally more infested. Besides common bean, genotypes with higher trichome densities are stimulant for whitefly oviposition in soybean (Valle and Lourenção, 2002), tomato (Toscano et al., 2002), and cotton (Chu et al., 2001). Therefore, trichome density should be avoided in genetic breeding programs for common bean, targeting the development of commercial cultivars less susceptible to whitefly.

In both the winter and rainy seasons, the upper part of plants was preferred for whitefly oviposition and adult infestation, whereas the lower part exhibited a higher number of nymphs. Overall, females prefer to oviposit on hosts that favor offspring development (Thompson, 1988). According to van Lenteren and Noldus (1990), whitefly preference for younger parts of common bean is due to greater nutrient concentrations, especially amino acids and reducing sugars, which are promptly available to feeding. Moreover, the authors added that younger leaves have thinner and softer cuticles and greater amounts of water than older leaves do. These features may facilitate whitefly oviposition and egg hydration, warranting higher survivorship of the immatures (Gill, 1990).

In both the winter and rainy seasons, whitefly infestations were higher at 25 and 32 DAE and decreased until the last sampling date (60 DAE). Our results agree with those of Jesus et al. (2010), who evaluated resistance of common bean genotypes to *B. tabaci* biotype B and found that the infestation was higher during the initial stages of plant development. Similar results were found by Toscano et al. (2002) and Campos et al. (2005) when assessing whitefly oviposition in tomato and cotton. In our study, at 25-32 DAE, plants of different cultivars were at growth stages V4 (third trifoliate open and plain) to R5 (first floral raceme in lower nodes, pre-flowering) (Fernandez et al., 1986). In this period, whiteflies are likely to encounter the best conditions for development, such as suitable chemical and morphological plant features (Walker and Perring, 1994). Studies should be conducted to further investigate these observations, since a similar condition was observed in tomato (Toscano et al., 2002) and cotton (Campos et al., 2005). Higher energy accumulation at this stage of development in plants with subsequent nutrient possibly shift from leaves to flowers and to fill pods and seeds (Marschner, 1995), which may explain population decline from this period to the last sampling date.

IPM for common bean was developed nearly two decades ago in Brazil, with economic thresholds established for the major common bean arthropod pests (Quintela, 2001). However, this program is not commonly practiced and common bean growers usually rely almost exclusively on application of synthetic insecticides for whitefly control. This probably occurs due to the absence of specific economic thresholds for *B. tabaci* biotype B, since it is the vector of the golden bean mosaic virus, major threat to common bean in Latin America (Morales and Anderson, 2001). The current economic threshold for whitefly is the simple presence of individuals in the crop (Quintela, 2001). To prevent whitefly damage, performance of practical and periodic samplings are necessary to detect the pest at initial colonization. In this study, adults preferred the upper part of plants, while nymphs were more abundant in the lower part. These results suggest that sampling in common bean fields should be directed toward leaves from the upper part of plants to obtain adult and egg counts or toward leaves from the lower part for nymph counts in order to achieve a reliable estimation of whitefly infestation level.

Common bean was more susceptible to whitefly attack at early stages of plant growth (25 and 32 DAE). This shows that insecticide seed treatment may be a viable option to slow whitefly population buildup as insecticide residual effects usually last 20-30 days. The choice of insecticide seed treatment over spraying at initial plant development is preferable to reduce mortality of natural enemies contributing with pest control (Silva et al., 2016). There are five commercial seed-treatment insecticides registered for whitefly control in common bean in Brazil, all neonicotinoids (thiamethoxam and imidacloprid) (MAPA, 2003). Furthermore, common bean resistant cultivars can be harmoniously coupled to chemical control, increasing efficacy of whitefly control (Janini et al., 2011).

In conclusion, cultivars IAC-Una and IPR-Eldorado were less preferred by whitefly oviposition in the winter season, while IAC-Una was less infested by adults. Cultivars IAPAR-81 and Guará were less oviposited and IAC-Centauro less infested by nymphs in the rainy season. Egg and adult infestations were higher in the upper part of plants, whereas nymphs were more abundant in the lower part. Higher incidence of *B. tabaci* biotype B occured at 25-32 DAE both in the winter and rainy seasons. Our results aid IPM of whitefly in common bean by providing recommended cultivars for specific seasons in Brazil, as well as which plant part and period of development should be the focus of samplings and control efforts. Our results could also serve as background for other studies aiming to evaluate mechanisms of plant resistance to insect pests and design IPM approaches.

A future study should replicate this experiment over multiple cropping seasons with highlighted cultivars to obtain consistent data on differential expression of resistance in function of varying climatic factors. Also, experiments in plant growth chambers with different environmental conditions, along with the analysis of gene expression, could reveal if common bean resistance to whitefly is influenced by abiotic factors.

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Conceptualization: Boiça Júnior, A.L.; Farias, P.R.S.; Carbonell, S.A.M.; Silva, A.G. Data acquisition: Silva, A.G.; Souza, B.H.S.; Rodrigues, N.E.L. Data analysis: Silva, A.G.; Souza, B.H.S. Design of methodology: Boiça Júnior, A.L.; Farias, P.R.S.; Silva, A.G. Writing and editing: Silva, A.G.; Souza, B.H.S.

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