Published November, 2011

Agronomic Application of Genetic Resources

Resistance of Tomato Subsamples to *Bemisia tabaci* Biotype B (Genn.) (Hemiptera: Aleyrodidae)

Maria Elisa de Sena Fernandes,* Derly José Henriques da Silva, Marcelo Coutinho Picanço,
Flávio Lemes Fernandes, Gulab Newandran Jham, and Pedro Crescêncio Souza Carneiro

ABSTRACT

Whitefly (*Bemisia tabaci*) causes damage to tomato (*Solanum lycopersicum* L.) and is controlled by insecticides harmful to man and the environment. Development of resistant cultivars is ideal for whitefly management, with alternate genetic sources being indispensable. Germplasm banks are potentially good sources of resistant cultivars. Agronomic characteristics of the tomato subsamples from the Horticultural Germplasm Bank (HGB) at Universidade Federal de Viçosa (UFV) have been typified but little is known about their insect resistance. Thus, the objective of this study was to assess the resistance of 103 HGB-UFV tomato subsamples to *B. tabaci* as well evaluate the resistance mechanism. The characteristics of the subsamples evaluated were the number of nymphs and eggs per plant and the resistance index compared with the susceptible cultivar Santa Clara, arbitrarily chosen as the susceptible standard. The trichome number per 0.04 cm^2 of the leaf blades and 15 leaf hydrocarbon concentrations were also determined. Resistant subsamples were submitted to antibiosis test and the mortality (%) and life cycle of the *B. tabaci* were evaluated. The difference in the number of eggs per plant, nymphs per plant, and nymph/egg ratio in the tomato subsamples was evaluated. A positive correlation was observed between the hydrocarbons undecane and tridecane with *B. tabaci* nymphs. Significant and positive differences in the trichome per 0.04-cm^2 density were found between the trichome density and the number of eggs per plant. The subsamples HGB-225, -327, -630, -813, -985, -2029, -2030, -2055, -2057, -2060, -2062, and -2068 were resistant to *B. tabaci* biotype B through antixenosis and antibiosis resistance mechanisms.

Insect pests and plant diseases are the main factors that reduce the productivity of the commercial tomato, with the whitefly *Bemisia tabaci* (Gennadius) (Hemiptera: Aleyrodidae) causing significant damage (Lima et al., 2000). *Bemisia tabaci* has an incomplete metamorphosis, with egg, nymph (first, second, third, and fourth instars), and adult phases (Bellows et al., 1994). Losses caused by the nymphs and adults can be either direct or indirect. Direct losses constitute sap sucking and toxin injection, affecting plant development and hence the quantity and quality of the final product (Toscano et al., 2004). Indirect loss is due to the transmission of the geminivirus (tomato yellow vein streak virus) disease, as well as sooty mold (*Capnodium* sp.), which reduce chlorophyll protein concentrations and the rate of photosynthesis (Hunter et al., 1998)

Whitefly of the *Bemisia* genus has become more important due to the introduction and dispersion of the biotype B, also referred to as *Bemisia argentifolii*, in North and South America and Europe. This biotype differs from the biotype A by its higher fecundity, higher number of hosts, resistance to several insecticides, and ability to induce more physiological abnormalities, such as silverleaf in cucurbits and irregular ripening of tomato fruits (Brown et al., 2000).

The main method for *B. tabaci* biotype B control is insecticides; however, they are often inefficient, pollute the environment, reduce natural enemies, and sort resistant biotypes (Bacci et al., 2007). Resistant tomato cultivars are considered to be ideal for *B. tabaci* management (Russell, 1978; Smith, 1989). Alternate genetic sources are indispensable in developing resistant cultivars, with germplasm banks being potentially important sources. Besides resistance, agronomic characteristics are highly desirable in breeding programs. Agronomic characteristics of the tomato subsamples from the HGB at UFV have been typified (Abreu et al., 2006) but little is known about their insect resistance (Oliveira et al., 2009). Despite the importance of breeding insect-resistant tomato cultivars, only a few such studies involving a few subsamples have been conducted (Suinaga et al., 2003, 2004). In addition, possible resistance mechanisms have not been investigated. Hence, the objective of this study was to evaluate the resistance of 103 HGB-UFV tomato subsamples to *B. tabaci* as well as to assess the resistance mechanism.

MATERIALS AND METHODS

Rearing of *Bemisia tabaci*

Adult whiteflies were collected from a commercial tomato plantation in Viçosa, MG, Brazil, and mailed for identification to Dr. Judith K. Brown, Department of Plant Science, University of Arizona, Tucson. After identification, the insects were reared in a greenhouse at UFV on cabbage (*Brassica oleracea* var.

M.E. de Sena Fernandes and D.J. Henriques, UFV, Dep. de Fitotecnia, Genética e Melhoramento de Plantas, Cep 36570-000 Viçosa, MG, Brazil; M.C. Picanço, UFV, Dep. de Biologia Animal, Campus Universitário, Cep 36570-000 Viçosa, MG, Brazil; F.L. Fernandes, Instituto de Ciências Agrárias, Campus de Rio Paranaíba, UFV, 38810-000 Rio Paranaíba, MG, Brazil; G. Newandram Jham, Dep. de Química, UFV, 36570-000 Viçosa, MG, Brazil; P.C.S. Carneiro, Dep. de Biologia Geral, UFV, 36570-000 Viçosa, MG, Brazil. Received 7 Feb. 2011. *Corresponding author (maria.sena@ufv.br).

Published in Agron. J. 103:1849–1861 (2011)
Posted online 5 Oct. 2011
doi:10.2134/agronj2011.0049

Abbreviations: HGB, Horticultural Germplasm Bank; UFV, Universidade Federal de Viçosa.

acephala DC.) cultivars and serralha-lisa (*Sonchus oleraceus* L.) (Panda and Khush, 1995), with weekly additions of cabbage, not infected with whitefly or other insects. The soil in the pots was irrigated twice a day. The average temperature in the greenhouse was 27 ± 7°C and the relative humidity was 65 ± 5%.

Resistance Mechanism of Tomato to *Bemisia tabaci*

Experiments were conducted in a greenhouse (6-m length by 5-m width by 3.5-m height at UFV). One hundred and three HGB-UFV tomato subsamples along with the cultivar Santa Clara (susceptibility standard to the whitefly) were used (Table 1).

Seeds were sown in polystyrene trays (68 by 34 cm) with 128 cells. Pine bark with vermiculite (Bioplant, Nova Ponte, MG, Brazil) was used as the substrate. Three to four tomato seeds were added to each cell. Seedlings were transplanted to 500-mL plastic containers containing dirt and tanned cow manure. The cultivation techniques used were described by Silva et al. (2008).

The experimental block design was entirely randomized with 104 treatments (103 subsamples plus Santa Clara) with three replicates. Each experimental plot consisted of a plastic vase with one tomato plant with six fully expanded leaves (about 20 d after transplant) placed on wooden benches (4-m length by 1.20-m width by 1.30-m height) in a greenhouse. At the beginning of the experiment, about 3600 adult whiteflies from insect colonies were released in the central part of the greenhouse.

Eggs from all parts of the plants were counted using a magnifying glass (20× magnification) after 6 d of infestation with adult insects. The nymph/egg ratio was calculated as

$$\frac{\text{nymphs}}{\text{egg}} = \frac{\text{nymphs/plant}}{\text{eggs/plant}}$$

The resistance index (RI) of the 103 tomato subsamples relative to Santa Clara was calculated. This procedure was used for all intensity characters (number of eggs and nymphs per plant and nymph/egg ratio) of *B. tabaci* attack using the following formula (Baldin et al., 2000):

$$\text{RI}_X = \left(\frac{X_\text{S} - X_\text{P}}{X_\text{S} + X_\text{P}}\right)100$$

where X is number of eggs and nymphs per plant and nymph/egg ratio; RI_X is the resistance index for the characteristic X; X_S is the characteristic X for the HSB tomato subsample; and X_P is the characteristic X for the susceptible standard (Santa Clara).

The confidence interval for the RI for Santa Clara was calculated for each characteristic evaluated and used as the standard to compare all the subsamples. The subsamples were classified as resistant, susceptible, or highly susceptible if the RI was lower, within, or higher than that of the Santa Clara confidence interval. This classification was based on the degree of resistance to insects (Lara, 1991).

The subsamples selected were submitted to antibiosis tests by removing one leaf from the median region and immersing its petiole in a plastic container with 100 mL of water to maintain leaf turgor. The container openings were sealed with hydrophobic cotton to avoid the death of *B. tabaci* adults by drowning. Each container containing one leaf of a subsample was placed in a plastic container (3 L), using a screen with a covered side opening to prevent insect attack. In the inner part of each bottle, 30 adult whiteflies were released and removed after 2 d. Eggs were counted with the help of a magnifying glass (20× magnification). Every 3 d, the number of nymphs and adults was counted. From these data, nymph and adult densities in each phase and the mortality percentage in each life cycle phase were calculated for all the subsamples.

Resistance Factors of Tomato to *Bemisia tabaci*

Trichome Density

The first fully expanded leaf from the plant apex was collected from each experimental plot and the number of trichomes on the first leaflet (0.04-cm^2 area) in the left region, without overlapping the nerve region, was evaluated. The trichome number was counted using a stereoscopic microscope (SMZ-140 Series, Motic, Xiamen, China) with 40× magnification.

Chemical Analysis

Leaves were removed from the plants and immediately cut with a pair of scissors into small pieces (approximately 1 cm in length) and 10 g of each subsample was placed in an Erlenmeyer flask and extracted with 250 mL of double-distilled hexane for 24 h. The hexane was evaporated to dryness at 45°C and the residue was stored in sealed glass vials (8 mL) in a freezer. For analysis, the residue was allowed to thaw to room temperature, diluted with hexane (1 mL), and analyzed by gas chromatography–mass spectrometry (GC–MS).

All data were obtained on a Shimadzu gas chromatograph–mass spectrometer (Model QP 5000, Shimadzu Corp., Kyoto, Japan) with the software program Class-5000, Version 1.2, an autosampler, a mass spectral database with 160,000 entries, and a DB-5 fused-silica capillary column (30 m by 0.25 mm, 0.25-µm µlm thickness) (Supelco, Bellefonte, PA). The oven temperature was increased from 20 to 80°C at 20°C/min and from 80 to 250°C at 8°C/min. Injector and transfer line temperatures were maintained at 280 and 300°C, respectively. The split ratio was 1:1 with He as the carrier gas at a flow rate of 1.2 mL/min (linear flow of 39.5 cm/s). Electron impact ionization mass spectra (70 eV) were recorded by scanning the mass spectrometer from *m/z* 29 to 320. To obtain representative data, the mass spectra of each GC peak (~50 scans) of interest was grouped and subtracted from the grouped mass spectra of the region closest (before or after) where no compound eluted.

The peaks were first identified by the GC–MS library system based on similarity indices. Final confirmation was made by comparing retention times with authentic hydrocarbon standards. Quantification was performed using the external standard method.

Statistical Analysis

Eggs per plant, nymphs per plant, nymph/egg ratio, and trichome density per 0.04 cm^2 data were submitted to Cochran and Lilliefors tests to verify if the data obeyed presuppositions of homogeneity variance and error normality (Cochran, 1947). Data were then submitted to variance analysis and their means were compared using the Scott–Knott test to group means ($P < 0.05$) (Scott and Knott, 1974).

Pearson correlations between *B. tabaci* attack and the hydrocarbon concentrations in the hexane leaf extract of the subsamples were conducted. Regression analysis of the number of eggs as a function of trichome density was also performed.

Table 1. Origin and collection year of the tomato subsamples from the Horticultural Germplasm Bank (HGB) at the Universidade Federal de Viçosa (source: www.ufv.br/bgh; verified 8 Aug. 2011).

Subsample	Origin	Year
HGB-24	Teóphyllo Otoni, MG, Brazil	1966
HGB-83	Feira de Santana, BA, Brazil	1966
HGB-121	Salvador, BA, Brazil	1966
HGB-161	Muribeca, BA, Brazil	1966
HGB-168	Maceió, AL, Brazil	1966
HGB-186	Vitória do Santo Antão, PE, Brazil	1966
HGB-216	Vitória do Santo Antão, PE, Brazil	1966
HGB-224	Alagoinha, BA, Brazil	1966
HGB-225	Alagoinha, BA, Brazil	1966
HGB-279	Goiás, GO, Brazil	1966
HGB-327	Estiva, GO, Brazil	1966
HGB-349	Estiva, GO, Brazil	1966
HGB-351	Jussara, GO, Brazil	1966
HGB-378	Itapirapuan, GO, Brazil	1966
HGB-468	Goiás, GO, Brazil	1966
HGB-603	Barbacena, MG, Brazil	1966
HGB-606	Barbacena, MG, Brazil	1966
HGB-630	São João Del Rei, MG, Brazil	1966
HGB-700	Cuiabá, MT, Brazil	1966
HGB-773	Porto Simão, MT, Brazil	1967
HGB-813	Cuiabá, MT, Brazil	1967
HGB-970	Campinas, SP, Brazil	1966
HGB-971	Campinas, SP, Brazil	1966
HGB-978	Campinas, SP, Brazil	1966
HGB-981	Campinas, SP, Brazil	1966
HGB-984	Campinas, SP, Brazil	1966
HGB-985	Campinas, SP, Brazil	1966
HGB-987	Campinas, SP, Brazil	1966
HGB-988	Campinas, SP, Brazil	1966
HGB-989	Campinas, SP, Brazil	1966
HGB-991	Campinas, SP, Brazil	1966
HGB-992	Campinas, SP, Brazil	1966
HGB-993	Campinas, SP, Brazil	1966
HGB-994	Campinas, SP, Brazil	1966
HGB-996	Campinas, SP, Brazil	1966
HGB-1019	Belo Horizonte, MG, Brazil	1967
HGB-1254	Goiânia, GO, Brazil	1969
HGB-1258	São Gonçalo, MT, Brazil	1969
HGB-1287	Londrina, PR, Brazil	1969
HGB-1490	São Paulo, SP, Brazil	1967
HGB-1497	São Paulo, SP, Brazil	1967
HGB-1498	São Paulo, SP, Brazil	1967
HGB-1532	Belo Horizonte, MG, Brazil	1967
HGB-1706	São Paulo, SP, Brazil	1967
HGB-1985	Purdue Univ., West Lafayette, IN	1966
HGB-1989	Purdue Univ., West Lafayette, IN	1966
HGB-1991	Purdue Univ., West Lafayette, IN	1966
HGB-2004	Purdue Univ., West Lafayette, IN	1966
HGB-2008	Purdue Univ., West Lafayette, IN	1966
HGB-2009	Purdue Univ., West Lafayette, IN	1966
HGB-2010	Purdue Univ., West Lafayette, IN	1966

(continued)

Table 1 (cont.)

Subsample	Origin	Year
HGB-2011	Purdue Univ., West Lafayette, IN	1966
HGB-2013	Purdue Univ., West Lafayette, IN	1966
HGB-2014	Purdue Univ., West Lafayette, IN	1966
HGB-2017	Purdue Univ., West Lafayette, IN	1966
HGB-2018	Purdue Univ., West Lafayette, IN	1966
HGB-2020	Purdue Univ., West Lafayette, IN	1966
HGB-2021	Purdue Univ., West Lafayette, IN	1966
HGB-2025	Purdue Univ., West Lafayette, IN	1966
HGB-2027	Purdue Univ., West Lafayette, IN	1966
HGB-2029	Purdue Univ., West Lafayette, IN	1966
HGB-2030	Purdue Univ., West Lafayette, IN	1966
HGB-2032	Purdue Univ., West Lafayette, IN	1966
HGB-2034	Purdue Univ., West Lafayette, IN	1966
HGB-2035	Purdue Univ., West Lafayette, IN	1966
HGB-2038	Purdue Univ., West Lafayette, IN	1966
HGB-2039	Purdue Univ., West Lafayette, IN	1966
HGB-2040	Purdue Univ., West Lafayette, IN	1966
HGB-2041	Purdue Univ., West Lafayette, IN	1966
HGB-2048	Purdue Univ., West Lafayette, IN	1966
HGB-2049	Purdue Univ., West Lafayette, IN	1966
HGB-2054	Purdue Univ., West Lafayette, IN	1966
HGB-2055	Purdue Univ., West Lafayette, IN	1966
HGB-2057	Purdue Univ., West Lafayette, IN	1966
HGB-2060	Purdue Univ., West Lafayette, IN	1966
HGB-2062	Purdue Univ., West Lafayette, IN	1966
HGB-2064	Purdue Univ., West Lafayette, IN	1966
HGB-2065	Purdue Univ., West Lafayette, IN	1966
HGB-2068	Purdue Univ., West Lafayette, IN	1966
HGB-2071	Purdue Univ., West Lafayette, IN	1966
HGB-2073	Purdue Univ., West Lafayette, IN	1966
HGB-2075	Purdue Univ., West Lafayette, IN	1966
HGB-2083	Purdue Univ., West Lafayette, IN	1966
HGB-2088	Purdue Univ., West Lafayette, IN	1966
HGB-2089	Purdue Univ., West Lafayette, IN	1966
HGB-2095	Purdue Univ., West Lafayette, IN	1966
HGB-2096	Purdue Univ., West Lafayette, IN	1966
HGB-2097	Purdue Univ., West Lafayette, IN	1966
HGB-2098	Purdue Univ., West Lafayette, IN	1966
HGB-2100	Purdue Univ., West Lafayette, IN	1966
HGB-2112	Purdue Univ., West Lafayette, IN	1966
HGB-2113	Purdue Univ., West Lafayette, IN	1966
HGB-2116	Purdue Univ., West Lafayette, IN	1966
HGB-2117	Purdue Univ., West Lafayette, IN	1966
HGB-2119	Purdue Univ., West Lafayette, IN	1966
HGB-2121	Purdue Univ., West Lafayette, IN	1966
HGB-2122	Purdue Univ., West Lafayette, IN	1966
HGB-2123	Purdue Univ., West Lafayette, IN	1966
HGB-2124	Purdue Univ., West Lafayette, IN	1966
HGB-2127	Purdue Univ., West Lafayette, IN	1966
HGB-2128	Purdue Univ., West Lafayette, IN	1966
HGB-2129	Purdue Univ., West Lafayette, IN	1966
HGB-2130	Purdue Univ., West Lafayette, IN	1966

RESULTS

Bemisia tabaci Egg Density

Significant differences were noted in the number of *B. tabaci* eggs and adult insects per plant [$F_{(103,208)} = 3.64$; $P < 0.0001$] among the subsamples. Fifty-three subsamples showed significantly fewer eggs than Santa Clara (Table 2). Based on the resistance index for the number of eggs per plant, subsamples HGB-225, -327, -468, -606, -630, -984, -985, -1019, -1287, -1991, -2009, -2010, -2030, -2034, -2041, -2048, -2060, -2062, -2073, -2075, and -2097 were classified as resistant to whitefly; subsamples HGB-981, -1254, -1497, and -2098 were classified as highly susceptible, while the remaining 79 subsamples were classified as highly susceptible (Fig. 1A).

Bemisia tabaci Nymph Density

Significant differences were observed in the number of *B. tabaci* nymphs perplant [$F_{(103,208)} = 6.00$; $P < 0.0001$] and *B. tabaci* nymph/egg ratio [$F_{(103,208)} = 3.48$; $P < 0.0001$] among the subsamples. Thirty-eight subsamples showed significantly fewer nymphs than Santa Clara (Table 3). Based on the resistance index for the number of nymphs per plant, the subsamples HGB-225, -327, -606, -2009, -2029, and -2060 were resistant to whitefly, while the remaining 97 subsamples were classified as susceptible (Fig. 1B).

Twenty-five subsamples showed significantly more nymphs than Santa Clara (Table 4). Based on the resistance index for the nymph/egg ratio, all the subsamples studied were classified as susceptible to *B. tabaci* attack (Fig. 1C).

In the antibiosis test, the mortality in the adult-egg phase for the subsamples HGB-2029, -2055, -985, and -327 was 89.75, 84.00, 83.95, and 67.11%, respectively. These mortalities were significantly higher than that recorded for Santa Clara (27.96%). The whitefly egg-to-adult life cycle was longer for the subsamples HGB-813 (36 d), -985 and -2029 (34 d), -2062, -2055, -327, and -2057 (approximately 33 d) than for Santa Clara (28 d) (Table 5).

Causes of Resistance to *Bemisia tabaci*

Morphological Causes

Significant differences among the subsamples were detected in the number of trichomes per 0.04 cm^2 [$F_{(103,208)} = 6.08$; $P < 0.0001$]. High trichome density was observed in the subsamples HGB-630, -1490, -2004, -2009, -2011, -2013, -2017, -2020, -2098, -2100, -2121, -2122, and -2130. A low trichome density was observed in the subsamples HGB-349, -773, -2029, and -2060 (Table 6). A positive and significant correlation was found between the trichome density in the subsamples and the number of eggs per plant ($Y = -0.88 + 0.09X$; $R^2 = 0.23$; $F = 85.75$; $P < 0.001$), suggesting that the subsamples with higher trichome density received greater oviposition of adult *B. tabaci*.

Chemical Causes

Fifteen hydrocarbons (C_9, nonane; C_{10}, decane; C_{11}, undecane; C_{12}, dodecane; C_{13}, tridecane; C_{14}, tetradecane; C_{15}, tetradecane; C_{16}, hexadecane; C_{17}, heptadecane; C_{18}, octadecane; C_{19}, nonadecane; C_{20}, eicosane; C_{21}, henecosane; C_{22}, docosane; and C_{24}, tetracosane) were quantified in the leaf extracts of 98 subsamples. No hydrocarbons were observed in the subsamples HGB-121, -186, -349, -1287, -2049, and -2097 (Table 7). Of the 15 hydrocarbons, only C_{11} and C_{13} were significantly correlated ($P < 0.05$) with the number of nymphs ($r = 0.24$ and 0.23, respectively).

DISCUSSION

Of the 103 subsamples, 55 had a low egg density per plant; 38 had lower nymph density per plant, and 79 subsamples had a lower nymph density per egg. The subsamples HGB-225, -327, -630, -813, -985, -2029, -2055, -2057, -2060, -2062, and -2068 were less attacked by *B. tabaci* for all traits evaluated in this study.

Few studies have investigated sources of resistance to *B. tabaci* in *S. lycopersicum* species (Oliveira et al., 2009). Most studies have been conducted with *Lycopersicon hirsutum* Donal, *L. hirsutum* Dunal forma *glabratum* C. H. Müll., *L. peruvianum* (L.) Mill., *L. pennellii* (Correll) D'Arcy, and *L. pimpinellifolium* (L.) Mill. (Fancelli and Vendramim, 2002; Toscano et al., 2002). Toscano et al. (2002) reported *B. tabaci* ovipostion of 2.3 ± 0.7 and 3.16 ± 2 in the subsamples PI-134417 of *L. hirsutum* f. *glabratum* and of LA 716 (*L. pennellii*), respectively, compared with 17.6 ± 7.8 in the susceptible Santa Clara. Based on lower oviposition, these subsamples were considered to be sources of resistance to this insect. Of the seven subsamples evaluated in preference tests by Fancelli and Vendramim (2002), only the subsamples LA 1739 of *L. hirsutum* and PI-134417 of *L. hirsutum* f. *glabratum* were less oviposited by *B. tabaci* than Santa Clara.

Other studies have reported differences in adult and nymph populations in different tomato subsamples. For example, Baldin et al. (2005) studied nine subsamples of *Lycopersicon* sp. and reported a lower number of adult *B. tabaci* in the subsample PI-134417 of *L. hirsutum* f. *glabratum* than IAC-Santa Clara. On the other hand, of the eight subsamples, only LA 716 of *L. pennellii* was less attacked than Santa Clara (Fancelli et al., 2005).

Low insect densities of eggs per plant and nymphs per plant of the subsamples HGB-225, -327, -813, -985, -2029, -2030, -2055, -2057, -2060, -2062, and -2068 could be associated with the antixenosis mechanism. Antixenosis is a resistance mechanism where insects exhibit a lower preference for oviposition, feeding, or shelter due to chemical stimulus or morphological or physical barriers (Panda and Khush, 1995). Antixenosis studies in arthropods have been conducted in tomato (*S. lycopersicum*) (Kennedy, 2003; Resende et al., 2006). Channarayappa et al. (1992) observed that the subsample LA 1777 of *L. hirsutum* f. *typicum* Humb. & Bonpl. expressed antixenosis resistance to the whitefly *B. tabaci*.

Another associated resistance mechanism is antibiosis, characterized by a negative effect on insect biology (Jindal et al., 2008). Morillo and Marcano (1997) and Pai and Shih (2003) reported that oviposition duration, nymph, and life cycle of the whitefly differed significantly in tomato subsamples. This mechanism has also been reported in cotton (*Gossypium hirsutum* L.), bean (*Phaseolus vulgaris* L.), and cucurbits (Soria et al., 1999; Jindal et al., 2008).

The antibiosis mechanism in our subsamples was apparently associated with a lower nymph/egg ratio in 73 out of the 103 subsamples studied. This low ratio demonstrated that these subsamples interfered with eclosion or caused nymph mortality (Panda and Khush, 1995). Antibiosis can also be related to adult mortality and insect life cycle duration (Panda and Khush, 1995). Tsai and Wang (1996) showed that host plants have a significant effect on the longevity and female oviposition

Table 2. Number (average ± standard error) of eggs per plant of the *Bemisia tabaci* biotype B (Hemiptera: Aleyrodidae) in the subsamples from the Horticultural Germplasm Bank (HGB) at the Universidade Federal de Viçosa.

Subsample	Eggs per plant†
HGB-981	100.00 ± 45.61 a
HGB-2098	63.33 ± 2.19 b
HGB-1254	57.67 ± 12.77 b
HGB-1497	55.00 ± 4.73 b
HGB-2121	43.33 ± 19.92 b
HGB-1989	42.67 ± 16.46 b
HGB-2011	41.00 ± 10.69 b
HGB-2095	32.33 ± 3.18 c
HGB-1258	30.00 ± 4.62 c
HGB-2088	28.67 ± 15.76 c
HGB-2021	26.67 ± 8.57 c
HGB-2008	26.67 ± 6.39 c
HGB-2096	26.33 ± 1.45 c
HGB-121	26.33 ± 3.76 c
HGB-2083	24.67 ± 6.64 c
HGB-1490	24.33 ± 2.91 c
HGB-2100	23.67 ± 8.41 c
HGB-378	22.67 ± 2.40 c
HGB-2089	22.33 ± 1.20 c
HGB-700	21.67 ± 3.53 c
HGB-993	20.67 ± 9.49 c
HGB-971	20.33 ± 3.76 c
HGB-2014	20.33 ± 7.22 c
HGB-1532	20.00 ± 1.15 c
HGB-2039	19.67 ± 2.60 c
HGB-1985	18.67 ± 7.75 c
HGB-83	18.33 ± 3.18 c
HGB-2040	18.33 ± 2.03 c
HGB-2054	18.33 ± 11.67 c
HGB-978	18.33 ± 16.37 c
HGB-2049	18.00 ± 4.62 c
HGB-989	18.00 ± 9.87 c
HGB-2004	16.67 ± 4.33 c
HGB-2123	16.67 ± 7.80 c
HGB-2130	16.33 ± 13.45 c
HGB-2017	16.33 ± 0.67 c
HGB-2122	16.00 ± 2.31 c
HGB-2027	15.67 ± 6.12 c
HGB-603	15.00 ± 10.07 c
HGB-970	15.00 ± 7.55 c
HGB-1498	15.00 ± 1.73 c
HGB-994	15.00 ± 1.73 c
HGB-2020	14.67 ± 5.49 c
HGB-2035	14.33 ± 4.91 c
HGB-2117	14.00 ± 2.31 c
HGB-1706	13.67 ± 8.09 c
HGB-2129	13.67 ± 3.18 c
HGB-988	13.33 ± 9.35 c
HGB-2112	13.00 ± 1.53 d
HGB-186	12.33 ± 12.33 d
HGB-2025	12.00 ± 2.08 d
HGB-2119	12.00 ± 1.73 d
HGB-216	11.33 ± 5.93 d
HGB-349	10.67 ± 4.70 d
HGB-992	10.33 ± 4.18 d
HGB-996	10.33 ± 10.33 d
HGB-2057	9.00 ± 6.66 d
HGB-991	8.67 ± 0.33 d
HGB-24	8.67 ± 0.33 d
HGB-2068	8.33 ± 2.60 d
HGB-2064	8.33 ± 2.73 d
HGB-2029	8.33 ± 8.33 d
HGB-2071	8.00 ± 8.00 d
HGB-2018	8.00 ± 1.15 d
HGB-2038	7.67 ± 7.67 d
HGB-224	7.67 ± 3.28 d
HGB-168	7.33 ± 7.33 d
HGB-2128	7.33 ± 4.33 d
HGB-2116	7.33 ± 3.18 d
HGB-2055	7.33 ± 2.19 d
HGB-2032	7.00 ± 0.58 d
HGB-2065	7.00 ± 0.58 d
HGB-161	7.00 ± 0.58 d
HGB-351	6.67 ± 3.18 d
HGB-773	6.33 ± 3.33 d
HGB-2113	6.33 ± 6.33 d
HGB-987	6.33 ± 2.91 d
HGB-813	6.33 ± 5.36 d
HGB-2127	6.00 ± 1.73 d
HGB-2013	5.33 ± 1.20 d
HGB-279	5.33 ± 4.37 d
HGB-2124	5.00 ± 2.89 d
HGB-2075	4.33 ± 4.33 d
HGB-2048	4.33 ± 4.33 d
HGB-2097	4.33 ± 4.33 d
HGB-1019	4.33 ± 4.33 d
HGB-225	4.33 ± 2.19 d
HGB-985	4.33 ± 2.60 d
HGB-630	4.33 ± 2.33 d
HGB-2034	4.00 ± 4.00 d
HGB-606	4.00 ± 1.15 d
HGB-2010	3.67 ± 2.03 d
HGB-468	3.33 ± 1.76 d
HGB-2060	3.33 ± 2.40 d
HGB-1991	3.33 ± 3.33 d
HGB-2073	3.00 ± 1.53 d
HGB-2030	3.00 ± 3.00 d
HGB-2041	2.67 ± 2.67 d
HGB-984	2.67 ± 2.19 d
HGB-2009	1.67 ± 0.88 d
HGB-1287	1.00 ± 0.58 d
HGB-327	1.00 ± 1.00 d
HGB-2062	0.00 ± 0.00 d
Santa Clara	16.33 ± 3.18 c

† Averages followed by the same letter in a column belong to the same group according to the Scott–Knott test at $P < 0.05$.

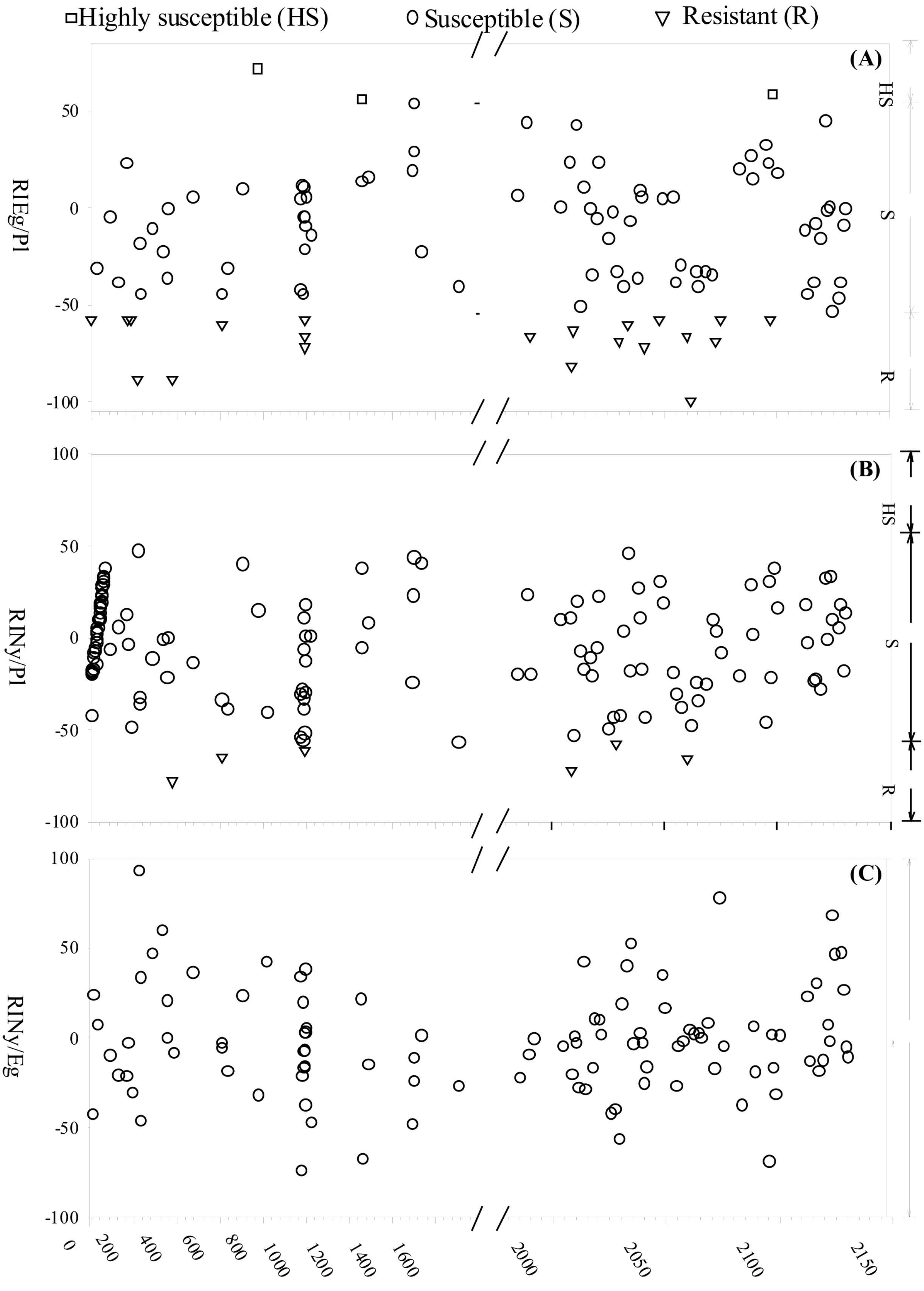

Fig. 1. Resistance index (RI) of the tomato subsamples from the Horticultural Germplasm Bank at Universidade Federal de Vicosa to *Bemisia tabaci* biotype B for (A) eggs per plant (RIEg/PI), (B) nymphs per plant (RINy/PI) and (C) nymph/egg ratio (RINy/Eg). Discontinuous horizontal lines delineate regions of the graph containing highly susceptible, susceptible, and resistant subsamples.

Table 3. Number (average ± standard error) of nymph/plant of *Bemisia tabaci* biotype B (Hemiptera: Aleyrodidae) in the subsamples from the Horticultural Germplasm Bank (HGB) at the Universidade Federal de Viçosa.

Subsample	Nymphs per plant†
HGB-1287	105.33 ± 0.88 a
HGB-2034	101.67 ± 0.88 a
HGB-1497	96.00 ± 22.54a
HGB-996	89.00 ± 0.58 a
HGB-1532	88.00 ± 16.74a
HGB-700	84.00 ± 15.04a
HGB-2098	83.00 ± 25.70a
HGB-2123	75.00 ± 20.21a
HGB-2121	73.67 ± 9.84 a
HGB-2096	71.33 ± 6.06 a
HGB-2048	71.00 ± 1.53 a
HGB-2088	67.67 ± 21.88a
HGB-2038	65.33 ± 0.88 b
HGB-1989	60.67 ± 1.76 b
HGB-1258	60.00 ± 9.81 b
HGB-2021	59.33 ± 9.84 b
HGB-2011	55.67 ± 8.37 b
HGB-2049	55.00 ± 5.20 b
HGB-83	54.33 ± 4.33 b
HGB-2112	53.67 ± 1.86 b
HGB-2128	53.67 ± 19.95b
HGB-2100	52.33 ± 16.05b
HGB-981	50.67 ± 9.94 b
HGB-2130	49.33 ± 30.33b
HGB-121	48.33 ± 18.10b
HGB-971	47.00 ± 4.36 b
HGB-2039	46.67 ± 2.60 b
HGB-2008	46.67 ± 13.02b
HGB-2071	45.67 ± 1.20 b
HGB-2004	45.67 ± 20.79b
HGB-2124	45.67 ± 5.49 b
HGB-378	44.33 ± 4.84 b
HGB-168	42.33 ± 1.45 c
HGB-2127	42.00 ± 8.39 c
HGB-2032	40.67 ± 15.30c
HGB-2073	40.33 ± 0.88 c
HGB-2089	39.33 ± 2.40 c
HGB-186	38.33 ± 0.88 c
HGB-1706	38.00 ± 13.58 c
HGB-992	36.67 ± 11.78 c
HGB-2122	36.67 ± 6.64 c
HGB-2113	35.67 ± 1.20 c
HGB-1019	35.00 ± 1.53 c
HGB-1254	34.00 ± 13.28 c
HGB-2020	34.00 ± 8.50 c
HGB-1498	33.33 ± 0.88 c
HGB-994	33.33 ± 17.61 c
HGB-2013	32.33 ± 3.18 c
HGB-2075	32.00 ± 0.58 c
HGB-2017	30.33 ± 5.49 c
HGB-988	30.00 ± 12.10 c
HGB-984	29.33 ± 11.89 c
HGB-978	28.67 ± 11.32 c
HGB-991	28.00 ± 5.69 c
HGB-2040	26.67 ± 3.76 c
HGB-2014	26.67 ± 7.22 c
HGB-2035	26.33 ± 0.33 c
HGB-2129	26.00 ± 9.07 c
HGB-2054	25.67 ± 6.36 c
HGB-1985	25.33 ± 5.78 c
HGB-1991	25.00 ± 0.58 c
HGB-2083	24.67 ± 1.45 c
HGB-2018	24.67 ± 0.88 c
HGB-2097	24.33 ± 0.88 c
HGB-224	24.33 ± 5.24 c
HGB-2117	23.67 ± 0.33 d
HGB-2116	23.33 ± 2.60 d
HGB-1490	23.00 ± 0.58 d
HGB-2064	23.00 ± 9.45 d
HGB-2068	22.33 ± 2.60 d
HGB-2119	21.33 ± 6.64 d
HGB-993	21.00 ± 7.21 d
HGB-468	20.33 ± 6.06 d
HGB-351	20.00 ± 5.20 d
HGB-2055	20.00 ± 8.96 d
HGB-773	19.33 ± 7.88 d
HGB-349	19.00 ± 6.11 d
HGB-813	18.67 ± 15.68 d
HGB-2065	18.33 ± 2.33 d
HGB-216	17.67 ± 1.86 d
HGB-2057	17.00 ± 3.79 d
HGB-24	16.67 ± 7.06 d
HGB-970	16.67 ± 7.80 d
HGB-279	16.00 ± 5.03 d
HGB-2030	15.33 ± 9.87 d
HGB-630	15.33 ± 7.88 d
HGB-2041	15.00 ± 0.58 d
HGB-2027	15.00 ± 4.04 d
HGB-2095	14.00 ± 5.20 d
HGB-2062	13.33 ± 4.48 d
HGB-985	13.00 ± 5.86 d
HGB-2025	12.67 ± 3.71 d
HGB-603	12.00 ± 5.77 d
HGB-2010	11.67 ± 1.20 d
HGB-989	11.33 ± 2.03 d
HGB-987	10.67 ± 1.76 d
HGB-161	10.33 ± 4.91 d
HGB-2029	10.00 ± 4.73 d
HGB-225	9.00 ± 2.65 d
HGB-606	8.00 ± 3.00 d
HGB-2060	7.67 ± 1.86 d
HGB-2009	6.00 ± 0.58 d
HGB-327	4.67 ± 1.20 d
Santa Clara	37.33 ± 8.09 c

† Averages followed by the same letter in a column belong to the same group according to the Scott–Knott test at $P < 0.05$.

(continued)

Table 3 (cont.)

Table 4. Nymph/egg ratios (average ± standard error) of *Bemisia tabaci* biotype B (Hemiptera: Aleyrodidae) in the subsamples from the Horticultural Germplasm Bank (HGB) at the Universidade Federal de Viçosa.

Subsample	nymph/egg ratio†
HGB-1287	78.25 ± 21.02 a
HGB-2073	22.00 ± 9.29 b
HGB-2123	14.14 ± 11.30 b
HGB-992	11.02 ± 9.25 c
HGB-2034	8.58 ± 0.00 c
HGB-988	7.68 ± 5.17 c
HGB-2127	7.46 ± 0.82 c
HGB-2124	7.35 ± 1.51 c
HGB-279	6.86 ± 5.02 d
HGB-2013	6.59 ± 1.21 d
HGB-2032	6.26 ± 2.73 d
HGB-984	6.21 ± 0.17 d
HGB-978	5.95 ± 4.73 d
HGB-351	5.60 ± 2.79 e
HGB-773	5.59 ± 3.21 e
HGB-2048	5.54 ± 0.00 e
HGB-2116	4.98 ± 2.28 e
HGB-2128	4.60 ± 2.78 e
HGB-1532	4.48 ± 1.05 e
HGB-700	4.31 ± 1.49 e
HGB-2112	4.22 ± 0.39 e
HGB-224	4.21 ± 1.29 e
HGB-987	4.14 ± 2.93 e
HGB-2030	3.89 ± 0.00 e
HGB-2049	3.69 ± 1.36 e
HGB-2018	3.25 ± 0.59 f
HGB-2020	3.21 ± 1.20 f
HGB-991	3.20 ± 0.57 f
HGB-2068	3.11 ± 0.72 f
HGB-83	3.10 ± 0.43 f
HGB-2121	3.04 ± 1.60 f
HGB-2088	3.01 ± 0.86 f
HGB-1706	2.95 ± 0.98 f
HGB-468	2.92 ± 0.34 f
HGB-2060	2.88 ± 1.33 f
HGB-996	2.84 ± 0.00 f
HGB-2038	2.78 ± 0.00 f
HGB-2064	2.77 ± 0.45 f
HGB-2021	2.72 ± 0.79 f
HGB-2096	2.71 ± 0.22 f
HGB-2100	2.70 ± 0.98 f
HGB-2009	2.67 ± 0.27 f
HGB-2065	2.62 ± 0.26 f
HGB-1019	2.62 ± 0.00 f
HGB-606	2.61 ± 1.49 f
HGB-1991	2.60 ± 0.00 f
HGB-2057	2.53 ± 1.69 f
HGB-2122	2.52 ± 0.80 f
HGB-2039	2.48 ± 0.40 f
HGB-813	2.47 ± 0.38 f
HGB-2010	2.46 ± 0.85 f
HGB-2035	2.45 ± 0.96 f
HGB-603	2.40 ± 1.20 f
HGB-971	2.40 ± 0.24 f
HGB-2004	2.39 ± 0.68 f
HGB-2055	2.39 ± 0.63 f
HGB-2075	2.38 ± 0.00 f
HGB-2129	2.36 ± 1.03 f
HGB-327	2.33 ± 0.00 f
HGB-1498	2.28 ± 0.24 f
HGB-1258	2.21 ± 0.69 f
HGB-1989	2.16 ± 1.01 f
HGB-2130	2.10 ± 0.35 f
HGB-378	2.06 ± 0.47 f
HGB-2119	2.03 ± 0.88 f
HGB-349	2.01 ± 0.64 f
HGB-994	2.00 ± 0.96 f
HGB-2113	2.00 ± 0.00 f
HGB-970	1.97 ± 1.52 f
HGB-24	1.92 ± 0.77 f
HGB-2041	1.88 ± 0.00 f
HGB-2017	1.86 ± 0.33 f
HGB-2097	1.85 ± 0.00 f
HGB-2071	1.83 ± 0.00 f
HGB-168	1.82 ± 0.00 f
HGB-993	1.79 ± 0.86 f
HGB-121	1.79 ± 0.49 f
HGB-2117	1.78 ± 0.28 f
HGB-2089	1.77 ± 0.10 f
HGB-2008	1.72 ± 0.09 f
HGB-1497	1.70 ± 0.28 f
HGB-1985	1.65 ± 0.49 f
HGB-161	1.59 ± 0.87 f
HGB-2040	1.54 ± 0.37 f
HGB-2054	1.49 ± 0.58 f
HGB-985	1.47 ± 0.79 f
HGB-2011	1.45 ± 0.18 f
HGB-2014	1.43 ± 0.17 f
HGB-981	1.43 ± 1.01 f
HGB-2098	1.34 ± 0.45 f
HGB-225	1.26 ± 0.49 f
HGB-2083	1.16 ± 0.29 f
HGB-630	1.11 ± 0.42 f
HGB-2027	1.09 ± 0.22 f
HGB-2025	1.03 ± 0.16 f
HGB-216	1.03 ± 0.27 f
HGB-186	1.00 ± 0.00 f
HGB-1490	0.98 ± 0.15 f
HGB-2029	0.68 ± 0.00 f
HGB-1254	0.54 ± 0.12 f
HGB-2095	0.43 ± 0.14 f
HGB-989	0.42 ± 0.02 f
HGB-2062	0.00 ± 0.00 f
Santa Clara	2.75 ± 1.20 f

†Averages followed by the same letter in a column belong to the same group according to the Scott–Knott test at $P < 0.05$.

Table 5. Number (average ± standard error) of eggs and adults per plant, mortality, and life cycle length of *Bemisia tabaci* biotype B (Hemiptera: Aleyrodidae) in the selected tomato subsamples with possible resistance factors (at 25 ± 2°C, 70 ± 5% relative humidity).

Subsample	Eggs per plant	Adults per plant	Mortality	Life cycle
			%	d
HGB-225	32.00 ± 3.00	20.00 ± 2.50	37.00 ± 1.75	29.00 ± 4.00
HGB-327	76.00 ± 2.00	25.00 ± 1.50	67.11 ± 0.95	33.00 ± 2.00
HGB-813	58.50 ± 2.86	37.50 ± 2.86	36.03 ± 1.76	36.00 ± 1.00
HGB-985	81.00 ± 1.50	13.00 ± 2.20	83.95 ± 2.00	34.00 ± 2.08
HGB-2029	45.50 ± 20.82	6.00 ± 4.08	89.75 ± 4.28	34.00 ± 2.08
HGB-2030	44.00 ± 4.90	13.00 ± 3.05	69.89 ± 3.35	29.00 ± 4.93
HGB-2055	25.00 ± 1.00	4.00 ± 2.80	84.00 ± 2.07	33.00 ± 4.00
HGB-2057	30.00 ± 2.00	14.00 ± 1.25	53.33 ± 1.58	33.00 ± 4.00
HGB-2060	80.00 ± 1.00	63.00 ± 2.55	21.25 ± 2.75	27.50 ± 2.04
HGB-2062	48.00 ± 12.25	28.50 ± 2.86	31.67 ± 23.39	33.33 ± 1.66
HGB-2068	48.50 ± 20.00	42.00 ± 21.23	20.09 ± 10.81	29.00 ± 3.05
Santa Clara	93.00 ± 1.50	67.00 ± 2.43	27.96 ± 1.45	28.33 ± 1.66

of *B. tabaci* B biotype. Life cycles longer than 25 d were reported by Villas Bôas et al. (2002), in agreement with the results found in some subsamples.

Higher trichome density in the subsamples HGB-1490, -2004, -2011, -2017, -2020, -2098, -2100, -2121, -2122, and -2130, associated with a higher number of whitefly eggs, apparently furnished a favorable microclimate for eggs (Butter and Vir, 1989). The female whitefly deposits eggs more frequently at the base of leaf trichomes (Vendramim et al., 2009). Such conditions provide enough relative humidity for the physiological processes to occur during the embryonic phase as well as protection against predators (Bernays and Graham, 1988). Trichomes also allow better nymph protection (Butter and Vir, 1989). Several studies have reported that high trichome density was positively correlated to *B. tabaci* oviposition in tomato, cotton, and soybean [*Glycine max* (L.) Merr.] (McAuslane, 1996; Chu et al., 2001; Toscano et al., 2002). Because offspring performance is determined by the choice of the adult insect for oviposition, a low trichome density in tomato leaves can be extremely important for the subsamples to be less visited by *B. tabaci* adults. This fact can be considered in breeding programs to select genes that express fewer numbers of trichomes. Some subsamples presented an unexpected response for the trichome × egg interaction. The subsamples HGB-630, -2009, and -2013 presented low egg densities of *B. tabaci* and high numbers of trichomes. On the other hand, the subsample HGB-981 presented a higher number of eggs and a low density of leaf trichomes.

Besides morphological factors, the presence of certain organic compounds, such as terpenes, phenols, and methyl ketones, among others (Suinaga et al., 1999; Kennedy, 2003; van Tol et al., 2007; Thompson, 1988; Resende et al., 2008) can affect insect behavior. These compounds can influence changes in feeding habits, oviposition, body weight, life cycle, and mortality through different mechanisms (Panda and Krush, 1995; Resende et al., 2008). No studies have associated these compounds with whitefly nymphs. The role of hydrocarbons in whitefly behavior has been little investigated (Hull-Sanders et al., 2007; Oliveira et al., 2009; Nerio et al., 2010; Nawrot et al., 2010).

Among the 15 hydrocarbons identified in this study, only undecane and tridecane concentrations resulted in positive correlations with nymphs per plant. Thus, compounds identified in the HGB subsamples could be associated with higher susceptibility to *B. tabaci* nymphs. The subsample HGB-2029 stood out because it caused high whitefly mortality; however, undecane and tridecane were not detected. The cultivar Santa Clara was the extreme opposite, being very susceptible to whitefly with high undecane and tridecane concentrations. Higher undecane and tridecane concentrations in Santa Clara, as opposed to their absence in subsample HGB-2029, could have attracted whitefly adults, encouraging higher oviposition and thus a higher number of nymphs. This is in agreement with Walling (2000) and Martinez de Ilarduya et al. (2003), who reported that tomato releases volatile compounds that attract *Macrosiphum euforbiae* (Hemiptera: Aphididae). Oliveira et al. (2009), investigating HGB subsamples, reported susceptibility to *Tuta absoluta* (Lepidoptera: Gelechiidae) in some tomato subsamples with these hydrocarbons. In addition to *S. lycopersicum*, other studies have reported hydrocarbon changes in insect feeding, oviposition, survival, and other traits (Hull-Sanders et al., 2007; Nerio et al., 2010; Nawrot et al., 2010). Thus, breeding programs should consider developing cultivars with low concentrations of volatile compounds and emphasize other compounds used against whiteflies.

The subsamples HGB-225, -327, -813, -985, -2029, -2030, -2055, -2057, -2060, -2062, and -2068 were resistant to *B. tabaci* biotype B through the antixenosis and antibiosis resistance mechanisms. Trichome density and some hydrocarbons explain the resistance of some subsamples. The subsample HGB-2029 appears to be the most promising because it influenced most significantly the biology of *B. tabaci* and should be further studied in breeding programs.

ACKNOWLEDGMENTS

We thank CAPES (Coordenação de Aperfeiçoamento de Pessoal de Nível Superior) and CNPq (Conselho Nacional de Desenvolvimento Científico e Tecnológico) for the scholarships and Mark Berhow of the USDA, Peoria, IL, for revising the manuscript.

Table 6. Number (average ± standard error) of trichomes per 0.04 cm^2 of leaf blade of the tomato subsamples from the Horticultural Germplasm Bank (HGB) at the Universidade Federal de Viçosa.

Subsample	Trichomes per 0.04 cm^2†
HGB-2011	365.67 ± 55.14 a
HGB-1490	364.00 ± 98.73 a
HGB-2121	337.67 ± 11.26 a
HGB-2098	320.00 ± 11.02 a
HGB-2009	316.67 ± 21.07 a
HGB-2020	303.00 ± 6.93 a
HGB-2004	303.00 ± 59.47 a
HGB-2122	296.33 ± 62.96 a
HGB-2100	288.33 ± 10.93 a
HGB-630	286.00 ± 12.49 a
HGB-2013	283.67 ± 19.92 a
HGB-2130	280.00 ± 90.84 a
HGB-2017	275.67 ± 53.98 a
HGB-1497	264.67 ± 1.20 b
HGB-2127	255.00 ± 33.49 b
HGB-2021	252.00 ± 45.90 b
HGB-1985	250.67 ± 35.51 b
HGB-2008	249.67 ± 25.69 b
HGB-1706	242.33 ± 65.89 b
HGB-1498	235.83 ± 57.53 b
HGB-978	226.67 ± 8.82 b
HGB-2116	224.50 ± 21.98 b
HGB-186	223.00 ± 0.00 b
HGB-2054	220.67 ± 26.19 b
HGB-2083	217.67 ± 36.66 b
HGB-2128	217.67 ± 14.72 b
HGB-994	210.00 ± 0.58 b
HGB-2129	201.67 ± 42.46 b
HGB-2018	200.67 ± 2.33 b
HGB-2010	200.00 ± 50.81 b
HGB-2057	196.67 ± 38.27 c
HGB-2014	193.00 ± 23.09 c
HGB-1254	189.00 ± 39.84 c
HGB-992	187.00 ± 1.53 c
HGB-468	180.67 ± 36.66 c
HGB-993	176.33 ± 16.22 c
HGB-2025	175.67 ± 2.33 c
HGB-2119	171.67 ± 37.24 c
HGB-2124	169.33 ± 0.67 c
HGB-327	168.00 ± 46.19 c
HGB-606	161.67 ± 37.82 c
HGB-603	161.33 ± 29.45 c
HGB-989	160.67 ± 47.05 c
HGB-1019	160.00 ± 0.58 c
HGB-2068	157.67 ± 36.38 c
HGB-2034	157.67 ± 0.33 c
HGB-2035	157.00 ± 0.58 c
HGB-351	156.33 ± 35.80 c
HGB-2027	153.33 ± 7.26 c
HGB-225	152.67 ± 34.35 c
HGB-984	152.00 ± 25.40 c
HGB-2071	149.67 ± 0.33 c
HGB-2039	146.00 ± 0.58 c
HGB-2089	145.33 ± 2.91 c
HGB-2096	144.00 ± 0.58 c
HGB-1287	142.33 ± 1.45 c
HGB-2032	141.33 ± 10.68 c
HGB-2073	138.67 ± 0.88 c
HGB-996	138.00 ± 0.58 c
HGB-1532	137.67 ± 40.19 c
HGB-2097	137.00 ± 0.58 c
HGB-2038	134.00 ± 0.58 d
HGB-2112	134.00 ± 40.45 d
HGB-1989	133.67 ± 40.70 d
HGB-2088	133.00 ± 40.82 d
HGB-1991	133.00 ± 40.82 d
HGB-2065	131.33 ± 23.17 d
HGB-279	130.00 ± 23.67 d
HGB-970	128.33 ± 24.55 d
HGB-2030	127.33 ± 10.97 d
HGB-83	126.67 ± 0.67 d
HGB-216	124.00 ± 13.00 d
HGB-971	124.00 ± 0.58 d
HGB-2123	124.00 ± 0.58 d
HGB-224	122.00 ± 18.48 d
HGB-168	121.33 ± 0.67 d
HGB-813	120.00 ± 25.12 d
HGB-2040	120.00 ± 0.58 d
HGB-985	119.33 ± 8.57 d
HGB-981	117.67 ± 1.45 d
HGB-2062	117.67 ± 12.99 d
HGB-378	116.00 ± 6.08 d
HGB-2048	115.00 ± 0.58 d
HGB-161	113.33 ± 10.40 d
HGB-700	113.00 ± 13.00 d
HGB-121	110.00 ± 0.58 d
HGB-2113	109.00 ± 0.58 d
HGB-991	105.67 ± 0.67 e
HGB-987	103.67 ± 11.57 e
HGB-2064	101.33 ± 3.28 e
HGB-24	99.33 ± 6.64 e
HGB-1258	98.67 ± 0.33 e
HGB-2117	98.00 ± 0.58 e
HGB-2055	96.33 ± 5.93 e
HGB-2075	94.00 ± 0.58 e
HGB-2049	91.00 ± 0.58 e
HGB-2041	91.00 ± 0.58 e
HGB-2095	87.00 ± 0.58 e
HGB-988	86.00 ± 3.06 e
HGB-773	81.67 ± 5.21 f
HGB-349	75.67 ± 2.03 f
HGB-2060	74.00 ± 6.66 f
HGB-2029	57.33 ± 8.25 g
Santa Clara	168.67 ± 30.85 c

† Averages followed by the same letter in a column belong to the same group according to the Scott–Knott test at $P < 0.05$.

Table 7. Concentrations of 15 hydrocarbons in the hexane leaf extracts of 103 tomato subsamples from the Horticultural Germplasm Bank (HGB) at the Universidade Federal de Viçosa and the cultivar Santa Clara (SC).

	Concentration†														
Subsample	C_9	C_{10}	C_{11}	C_{12}	C_{13}	C_{14}	C_{15}	C_{16}	C_{17}	C_{18}	C_{19}	C_{20}	C_{21}	C_{22}	C_{24}
	g/kg of leaves based on fresh weight														
SC											67.3	6			8.5
HGB-24												21			
HGB-83			74.8		17.3	23.2					56.3	9			
HGB-161	3757.4														36
HGB-168						8	3.4	3.3			10	0.5			
HGB-216												6	6		3
HGB-224												1			40
HGB-225												10	7		33
HGB-279		39.45	25.1												15
HGB-327												3.7			
HGB-351												1			4.6
HGB-378												4.5			15
HGB-468												5.3	9.5		16
HGB-603										3		1.5			12.6
HGB-606												4.2			7
HGB-630															8.5
HGB-700													5		73
HGB-773		31.7										24			
HGB-813													121		5.4
HGB-970	809											5.5	18		341
HGB-971					3.4						34	11			
HGB-978												10.5			13
HGB-981												3			4
HGB-984															1.6
HGB-985												6			333
HGB-987					6.3						7	20	7		54
HGB-988	2924														
HGB-991															2.5
HGB-992												7.2			388
HGB-993															9
HGB-994											151.5	69			
HGB-996		4.1													
HGB-1019		131.8	195		18.1	21.5	6.3	7		7	62	16	79		
HGB-1254												3			13
HGB-1258												7			5.5
HGB-1490													5		
HGB-1497								2.3	3.3						48
HGB-1498										6.5	15.6	1.7			138
HGB-1532					13.3	14.5	6	11			33	1	97		
HGB-1706											6	2.6			173
HGB-1985												1.2	85.5		427
HGB-1991												14			
HGB-1999													121		540
HGB-2004			9.4			9.0	4.7					3.5			35
HGB-2008												13			103
HGB-2009							5	4.5	4.7			5			48
HGB-2010						4.6	4	3.3	3.7	3	6	0.5			132
HGB-2011	4.4											9			
HGB-2013						9	6.2	5.5				2			18
HGB-2014						4.5	15.7	10.3	8.5			9			24
HGB-2017							5	5.4	6.2	4.5	7	11	8		

(continued)

Table 7 (cont.)

	Concentration†														
Subsample	C_9	C_{10}	C_{11}	C_{12}	C_{13}	C_{14}	C_{15}	C_{16}	C_{17}	C_{18}	C_{19}	C_{20}	C_{21}	C_{22}	C_{24}
HGB-2018															37
HGB-2020													16		
HGB-2021							6	6				8			197
HGB-2025															3.3
HGB-2027			4.6		3.5										7.3
HGB-2029								1.5				4			
HGB-2030															1.5
HGB-2032			13.7	11	14.1	25	9	10		7		11			17.7
HGB-2034												5			
HGB-2035			9			6	2.2	2.7		3	24				
HGB-2038				12	10.8	13.8	5	6.2	6		36	1			
HGB-2039			51.3			17.7	6				30	6.5			50
HGB-2040						6.5	3		4	3.5	7	27		3	
HGB-2041		15.0				10.2	3				44	30			
HGB-2048											6				
HGB-2054											31	6			67.7
HGB-2055															47.2
HGB-2057												1.5			6
HGB-2060												24			34
HGB-2062												4			30
HGB-2064												7.8			77
HGB-2065												2.2		145	
HGB-2067															63
HGB-2068												7			5
HGB-2072												4.4	85		
HGB-2075					9	15.2	5.2	1.5			33	1.3			
HGB-2083						15					43	12			473
HGB-2088															66.7
HGB-2089															61.3
HGB-2095							3	5		5	33	1.2			
HGB-2096											14, 6	5			
HGB-2098							3.20	3.7	4			1			92.2
HGB-2100															4.4
HGB-2112		4.1				6	2.5				6				70
HGB-2113			17.7								7				
HGB-2116												11			192
HGB-2119											34				290
HGB-2121						18	11				24	13			487
HGB-2122								5.4	9	7	29	15.6		27	215
HGB-2123	31.7				14.2						26	17.5			31
HGB-2124							44	28	19.4					35	501
HGB-2127											20	14			3
HGB-2128							1.5	2	3						29
HGB-2129															4
HGB-2130												2.2			43

† C_9, nonane; C_{10}, decane; C_{11}, undecane; C_{12}, dodecane; C_{13}, tridecane; C_{14}, tetradecane; C_{15}, tetradecane; C_{16}, hexadecane; C_{17}, heptadecane; C_{18}, octadecane; C_{19}, nonadecano; C_{20}, eicosane; C_{21}, henecosane; C_{22}, docosane; C_{24}, tetracosane. No hydrocarbons were detected in the subsamples HGB-121, -186, -349, -1287, -2049, and -2097.

REFERENCES

Abreu, F.B., D.J.H. Silva, B.G. Marim, P.C.S. Carneiro, A.C.P. Juhasz, C.A.C. Luca, R.F. Valente, and M.A. Guimarães. 2006. Minimum number and best combinations of harvests to evaluate accessions of tomato plants from germplasm banks. Genet. Mol. Biol. 29:112–116. doi:10.1590/S1415-47572006000100021

Bacci, L., A.L.B. Crespo, T.L. Galvan, E.J.G. Pereira, M.C. Picanço, G.A. Silva, and M. Chediak. 2007. Toxicity of insecticides to the sweetpotato whitefly (Hemiptera: Aleyrodidae) and its natural enemies. Pest Manage. Sci. 63:699–706. doi:10.1002/ps.1393

Baldin, E.L.L., L.C. Toscano, A.C.S. Lima, F.M. Lara, and A.L. Boiça, Jr. 2000. Preferência para oviposição de *Bemisia tabaci* biótipo "B" por genótipos de *Curcubita moschata* e *Curcubita máxima*. Bol. Sanid. Veg. Plagas 26:409–413.

Baldin, E.L.L., J.D. Vendramim, and A.L. Lourenção. 2005. Resistance of tomato genotypes to the whitefly *Bemisia tabaci* (Gennadius) biotype B (Hemiptera: Aleyrodidae). (In Portuguese, with English abstract.) Neotrop. Entomol. 34:435–441. doi:10.1590/S1519-566X2005000300012

Bellows, T.S., Jr., T.M. Perring, R.J. Gill, and D.H. Headrick. 1994. Description of a species of *Bemisia* (Homoptera: Aleyrodidae). Ann. Entomol. Soc. Am. 87:195–206.

Bernays, E.A., and M. Graham. 1988. On the evolution of host specificity in phytophagous arthropods. Ecology 69:886–892. doi:10.2307/1941237

Brown, J.K., A.M. Idris, M.W. Olsen, M.E. Miller, T. Isakeit, and J. Anciso. 2000. Curcubit leaf curl virus, a new whitefly transmitted geminivirus in Arizona, Texas, and Mexico. Plant Dis. 84:809. doi:10.1094/PDIS.2000.84.7.809A

Butter, N.S., and B.K. Vir. 1989. Morphological basis of resistance in cotton to the whitefly *Bemisia tabaci*. Phytoparasitica 17:251–261. doi:10.1007/BF02980754

Channarayappa, C., G. Shivashankar, and V. Muniyappa. 1992. Resistance of *Lycopersicon* species to *Bemisia tabaci*, a tomato leaf curl virus vector. Can. J. Bot. 70:2184–2192. doi:10.1139/b92-270

Chu, C.C., T.P. Freeman, J.S. Buckner, T.J. Henneberry, D.R. Nelson, and E.T. Natwick. 2001. Susceptibility of upland cotton cultivars to *Bemisia tabaci* biotype B (Homoptera: Aleyrodidae) in relation to leaf age and trichome density. Ann. Entomol. Soc. Am. 94:743–749. doi:10.1603/0013-8746(2001)094[0743:SOUCCT]2.0.CO;2

Cochran, W.G. 1947. Some consequences when the assumptions for the analysis of variance are not satisfied. Biometrics 3:22–38. doi:10.2307/3001535

Fancelli, M., and J.D. Vendramim. 2002. Development of *Bemisia tabaci* (Gennadius, 1889) biotype on *Lycopersicon* spp. genotypes. Sci. Agric. 59:665–669.

Fancelli, M., J.D. Vendramim, R.T.S. Frighetto, and L. Lourenção. 2005. Glandular exudate of tomato genotypes and development of *Bemisia tabaci* (Genn.) (Sternorryncha: Aleyrodidae) biotype B. (In Portuguese, with English abstract.) Neotrop. Entomol. 34:659–665. doi:10.1590/S1519-566X2005000400017

Hull-Sanders, H.M., R. Clare, R.H. Johnson, and G.A. Meyer. 2007. Evaluation of the evolution of increased competitive ability (EICA) hypothesis: Loss of defense against generalist but not specialist herbivores. J. Chem. Ecol. 33:781–799. doi:10.1007/s10886-007-9252-y

Hunter, W.B., E. Hiebert, S.E. Webb, J.H. Tsai, and J.E.L. Poston. 1998. Location of geminiviruses in the whitefly *Bemisia tabaci* (Homoptera: Aleyrodidae). Plant Dis. 82:1147–1151. doi:10.1094/PDIS.1998.82.10.1147

Jindal, V., G.S. Dhaliwal, and A.K. Dhawan. 2008. Mechanisms of resistance in cotton to whitefly *Bemisia tabaci* (Homoptera: Aleyrodidae): Antibiosis. Int. J. Trop. Insect Sci. 27:216–222. doi:10.1017/S1742758407849290

Kennedy, G.G. 2003. Tomato, pests, parasitoids, and predators: Tritrophic interactions involving the genus *Lycopersicon*. Annu. Rev. Entomol. 48:51–72. doi:10.1146/annurev.ento.48.091801.112733

Lara, F.M. 1991. Princípios de resistência de plantas a insetos. Ícone, São Paulo, Brazil.

Lima, L.H.C., M.C. Moretzohn, and M.R.V. Oliveira. 2000. Survey of *Bemisia tabaci* (Gennadius) (Hemiptera: Aleyrodidae) biotypes in Brazil using RAPD markers. Genet. Mol. Biol. 23:781–785. doi:10.1590/S1415-47572000000400012

Martinez de Ilarduya, O.M., Q.G. Xie, and I. Kaloshian. 2003. Aphid induced defense responses in *Mi-1*-mediated compatible and incompatible tomato interactions. Mol. Plant Microbe Interact. 16:699–708. doi:10.1094/MPMI.2003.16.8.699

McAuslane, H.J. 1996. Influence of leaf pubescence on ovipositional preference of *Bemisia argentifolii* (Homoptera, Aleyrodidae) on soybean. Environ. Entomol. 25:834–841.

Morillo, F.E., and R.V.B. Marcano. 1997. Development of the whitefly on different genotypes of tomato. (In Spanish, English summary.) Agron. Trop. 47:271–286.

Nawrot, J., M. Gawlak, J. Szafranek, B. Szafranek, E. Synak, J.R. Warchalewski, D. Piasecka-Kwiatkowska, W. Blaszczak, T. Jeliński, and J. Fornal. 2010. The effect of wheat grain composition, cuticular lipids and kernel surface microstructure on feeding, egg-laying, and the development of the granary weevil, *Sitophilus granarius* (L.). J. Stored Prod. Res. 46:133–141.

Nerio, L.S., J. Olivero-Verbel, and E. Stashenko. 2010. Repellent activity of essential oils: A review. Bioresour. Technol. 101:372–378. doi:10.1016/j.biortech.2009.07.048

Oliveira, F.A., D.J.H. Silva, G.L.D. Leite, G.N. Jham, and M.C. Picanço. 2009. Resistance of 57 greenhouse-grown accessions of *Lycopersicon esculentum* and three cultivars to *Tuta absoluta* (Meyrick) (Lepidoptera: Gelechiidae). Sci. Hortic. 119:182–187. doi:10.1016/j.scienta.2008.07.012

Pai, K.F., and C.I.T. Shih. 2003. Population parameters of *Bemisia argentifolii* Bellows and Perring (Homoptera: Aleyrodidae) on cucumber. Plant Prot. Bull. 45:91–100.

Panda, N., and G.S. Khush. 1995. Host plant resistance to insects. CABI, Wallingford, UK.

Resende, J.T.V., W.R. Maluf, M.G. Cardoso, M.V. Faria, L.D. Gonçalves, and I.R. Nascimento. 2008. Resistance of tomato genotypes with high level of acylsugars to *Tetranychus evansi* Baker and Pritchard. Sci. Agric. 65:31–35. doi:10.1590/S0103-90162008000100005

Resende, J.T.V.R., W.R. Maluf, M.V. Faria, A.Z. Pfann, and I.R. Nascimento. 2006. Acylsugars in tomato leaflets confer resistance to the South American tomato pinworm, *Tuta absoluta* Meyr. Sci. Agric. 63:20–25. doi:10.1590/S0103-90162006000100004

Russell, G.E. 1978. Plant breeding for pest and disease resistance. Butterworths, London.

Scott, A.J., and M.A. Knott. 1974. A cluster analysis method for grouping means in the analysis of variance. Biometrics 30:507–512. doi:10.2307/2529204

Silva, D.J.H., F.B. Abreu, F.R.B. Caliman, and A.C. Antônio. 2008. Origin, cultivation techniques and germplasm resources. p. 3–25. *In* V.R. Preedy and R.R. Watson (ed.) Tomatoes and tomato products: Nutritional, medicinal and therapeutic properties. Science Publ., Enfield, CT.

Smith, C.M. 1989. Plant resistance to insects: A fundamental approach. John Wiley & Sons, New York.

Soria, C., A. Lopez Sese, and G.M.L. Gomez. 1999. Resistance of *Cucumis melo* against *Bemisia tabaci* (Homoptera: Aleyrodidae). Environ. Entomol. 28:831–835.

Suinaga, F.A., V.W.D. Casali, D.J.H. Silva, and M.C. Picanço. 2003. Dissimilaridade genética de fontes de resistência de *Lycopersicum* spp. a *Tuta absoluta* (Meyrick, 1917) (Lepidoptera: Gelechiidae). R. Bras. Agrociencia 9:371–376.

Suinaga, F.A., M.C. Picanço, G.N. Jham, and S.H. Brommonschenkel. 1999. Causas químicas de resistência de *Lycopersicum peruvianum* (L.) a *Tuta absoluta* (Meyrick) (Lepidoptera: Gelechiidae). (In Portuguese, with English abstract.) An. Soc. Entomol. Bras. 28:313–321. doi:10.1590/S0301-80591999000200015

Suinaga, F.A., M.C. Picanço, M.D. Moreira, A.A. Semeão, and S.T.V. Magalhães. 2004. Resistência por antibiose de *Lycopersicon peruvianum* à traça do tomateiro. (In Portuguese, with English abstract.) Hortic. Bras. 22:281–285. doi:10.1590/S0102-05362004000200023

Thompson, J.N. 1988. Evolutionary ecology of the relationship between oviposition preference and performance of offspring in phytophagous insects. Entomol. Exp. Appl. 47:3–14. doi:10.1111/j.1570-7458.1988.tb02275.x

Toscano, L.C., A.L. Boiça, Jr., and W.I. Maruyama. 2002. Nonpreference of whitefly for oviposition in tomato genotypes. Sci. Agric. 59:677–681. doi:10.1590/S0103-90162002000400009

Toscano, L.C., A.L. Boiça, Jr., and W.I. Maruyama. 2004. Assessment of physiological aspects of three tomato genotypes infested by *Bemisia tabaci* (Gennadius) biotype B (Hemiptera: Aleyrodidae). Neotrop. Entomol. 33:777–782. doi:10.1590/S1519-566X2004000600016

Tsai, J.H., and K. Wang. 1996. Development and reproduction of *Bemisia argentifolii* on five host plants. Environ. Entomol. 25:810–816.

van Tol, R.W., H.J. Swarts, A. VanderLinden, and J.H. Visser. 2007. Repellence of the red bud borer *Resseliella oculiperda* from grafted apple trees by impregnation of rubber budding strips with essential oils. Pest Manage. Sci. 63:483–490. doi:10.1002/ps.1374

Vendramim, J.D., A.P. Souza, and M.G. Ongarelli. 2009. Oviposition behavior of the silverleaf whitefly *Bemisia tabaci* biotype B on tomato. (In Portuguese, with English abstract.) Neotrop. Entomol. 38:126–132. doi:10.1590/S1519-566X2009000100014

Villas Bôas, G.L., F.H. França, and N. Macedo. 2002. Potencial biótico da mosca branca *Bemisia argentifolii* a diferentes plantas hospedeiras. (In Portuguese, with English abstract.) Hortic. Bras. 20:71–79. doi:10.1590/S0102-05362002000100014

Walling, L.L. 2000. The myriad plant responses to herbivores. J. Plant Growth Regul. 19:195–216.