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Abstract

Sweetpotato whitefly, *Bemisia tabaci*, is a key greenhouse tomato pest. We evaluated five cultivars in randomized blocks under low, moderate, and high starting infestations. Adults per third fully expanded leaf were counted weekly for four weeks and analyzed (ANOVA/Tukey). Under low pressure, cultivars did not differ early, but by Week 4, ‘Husky Cherry’ and ‘Better Boy’ were highest, ‘Roma’ intermediate, and ‘Sweet 100’ and ‘Beefsteak’ lowest. Under moderate pressure, differences were transient. Under high pressure, no differences were detected. Cultivar effects were therefore pressure-dependent. Selection can aid management at low pressure, whereas higher pressures require broader IPM.

Abbreviations: Integrated pest management (IPM), tomato yellow leaf curl virus (TYLCV), Host plant resistance (HPR), Sweetpotato whitefly (SPWF)

Keywords: *Bemisia tabaci*, Host plant resistance, Population dynamics, Integrated Pest Management

Introduction

Controlled environment tomato production in the U.S. Southeast provides the warm, stable microclimate that favors sweetpotato whitefly, *Bemisia tabaci* Gennadius (Hemiptera: Aleyrodidae), a key pest that reduces vigor directly and vectors begomoviruses such as tomato yellow leaf curl virus (TYLCV). Limiting vector abundance is central to disease prevention, yet chemical control alone is not sufficient and might quickly develop resistance and environmental risks. Stansly et al. (2004) show how exclusion and TYLCV-tolerant cultivars created conditions for effective biological control in Mediterranean greenhouse tomatoes. Structural tactics (fine-mesh or UV-absorbing screens) may be helpful but can introduce heat and ventilation tradeoffs (Lapidot et al., 2001; Arnemann et al., 2019). Managing adults early is also critical to reduce pest build up, and restrict virus spread and transmission efficiency.

Host plant resistance (HPR) is a foundational IPM tactic, historically effective and broadly compatible with other controls. Classical and updated HPR frameworks distinguish antixenosis, antibiosis, and tolerance, as well as constitutive versus induced defenses (Souza, 2025). In tomato, resistance to *B. tabaci* often involves glandular trichomes and specialized metabolites (e.g., acylsugars, sesquiterpenes) (Rutz et al., 2024). Moreover, emerging work shows additional phloem-based defenses that specifically hinder nymphal development. In wild *Solanum chmielewskii*, elevated riboflavin in the vasculature is linked to delayed nymphal development and can be transferred via grafting (Denkers et al., 2025). Therefore, it is critical to consider different cultivars for management of whiteflies in the context of HPR traits, especially for potential integrative management with other control methods (Perier et al., 2022).

Despite this progress, cultivar effects are frequently tested under unspecified or heterogeneous starting pest pressure, making it difficult to separate true host effects from background immigration or position effects in greenhouses. Standardized, transparent HPR metrics have been urged to improve inference and on-farm relevance (Souza, 2025), and early, threshold-based interventions underscore how initial pressure shapes outcomes (Arnemann et al., 2019). Motivated by these gaps, this study compared five greenhouse tomato cultivars across low, moderate, and high initial

whitefly pressure in a greenhouse with randomized complete block design, quantifying *B. tabaci* adult abundance on the third fully expanded leaf weekly for four weeks to resolve pressure-dependent host effects while accounting for positional variance.

Materials and Methods

Insects and rearing

Sweetpotato whitefly (SPWF) adults were collected from rosemary in greenhouse facilities near Union Springs, Alabama (32°06′47″N, 85°43′31″W) in August 2024. Colonies were maintained under controlled greenhouse conditions (28 ± 2 °C, 60 ± 10% RH, 14:10 h L:D) on mixed, pesticide-free cucumber and cotton plants provided *ad libitum*. Source plants were replaced as needed to maintain colony vigor. No insecticides were applied to colonies during the study.

Plant material and greenhouse conditions

Five tomato cultivars, ‘Husky Cherry’, ‘Better Boy’, ‘Roma’, ‘Beefsteak’, and ‘Sweet 100’, were obtained as uniform transplants (~3-week-old plugs) from Bonnie Plants (Union Springs, AL). Plugs were transplanted singly into 8.0-L pots filled with a peat moss:vermiculite substrate (≈ 2:1, v/v) and amended with a controlled-release fertilizer (Osmocote® Smart Release® 15-9-12 NPK, 40 g pot^{-1}). Plants were lightly irrigated twice a day to avoid water stress under automated irrigation lines in a uniform way and grown under the same greenhouse conditions used for insect colonies. Each pot containing one plant constituted an experimental unit. Plants were spaced to prevent canopy contact and rotated within blocks at each census to minimize positional artifacts.

Experimental design and initial infestation calibration

The experiment comprised three independent runs at contrasting initial SPWF pressure (low, moderate, high). Initial pressure was standardized at the plant level using counts on the third fully expanded leaf from the apex (hereafter, “experimental leaf”), following a common standardization practice for whitefly–tomato assays (adapted from Rodríguez-López et al., 2011). Adults were introduced from the colony using *B. tabaci*-

infested inoculation plants (cotton or cucumber). Inoculation plants were interspersed among experimental tomatoes in the open greenhouse. After 24 h, adults present on each experimental leaf were counted to verify target levels. Target ranges were: Low at ~1-2 average adults per experimental leaf; Moderate at ~10 average adults per experimental leaf; and High at >20 average adults per experimental leaf. The three runs were conducted at different times to isolate initial-level effects: 16 Oct 2024 (moderate), 24 Feb 2025 (high), and 13 May 2025 (low).

Layout and randomization

Within each run, plants were arranged as a randomized complete block design (RCBD) with five blocks (capturing light/airflow gradients typical of greenhouses). Each block contained all five cultivars. There were four replicates per cultivar under low and high pressure and five replicates per cultivar under moderate pressure. Treatment positions within blocks were randomized using a computer-generated sequence.

Response variable and sampling

The response variable was the number of SPWF adults observed on the experimental leaf. Counts were taken weekly for four consecutive weeks (Weeks 1–4) between 09:00 and 12:00 to reduce diurnal variability. Observers inspected both leaf surfaces. If the experimental leaf was damaged or abscised, the next fully expanded leaf below was used and recorded. No leaves were detached for counting. Plants that died or were heavily damaged by non-target factors were excluded *a priori* and not replaced after Week 1.

Statistical analysis

Analyses were conducted separately for each initial pressure run and each week to resolve short-term cultivar separation while controlling for positional effects. For each run × week, we fit an ANOVA (RCBD) with cultivar and block as fixed effects. Model assumptions were evaluated via residual diagnostics – histograms, Q-Q plots, and residuals-versus-fitted – following standard guidance (Fernandez, 1992). Homoscedasticity patterns were consistent with the ANOVA framework, and no variance-stabilizing transformations were required (no nullities observed). When

assumptions were reasonable, we reported F and p values for cultivar and block and conducted Tukey's HSD for pairwise comparisons among cultivars ($\alpha = 0.05$). To complement these parametric analyses for count data and to check robustness under potential overdispersion, we pre-specified a negative binomial GLM (log link) as a sensitivity analysis, with likelihood-ratio tests for cultivar and block and estimated marginal means on the response scale with Tukey adjustment. Summary tables report means ± standard errors (SE) by cultivar and week. Analyses were performed in R (v4.5.1) using *car* (diagnostics), *emmeans* (EMMs and Tukey contrasts), *multcomp/multcompView* (grouping letters), and *tidyverse* for data handling.

Results

Cultivar effects

Cultivar effects depended strongly on the initial whitefly pressure (Table 1).
Under low pressure, cultivar was not significant in Week 1 ($p = 0.091$) or Week 2 ($p = 0.056$) but became highly significant in Weeks 3 and 4 ($p < 0.001$). Block effects were significant in Weeks 1-3 ($p \leq 0.027$) but mitigated after Week 4 ($p = 0.181$), indicating modest positional heterogeneity early that subsided later. Under moderate pressure, cultivar effects were intermittent: significant in Week 1 ($p = 0.023$) and Week 3 ($p = 0.042$), but not Weeks 2 or 4 ($p \geq 0.236$). Block effects were consistently strong across all weeks ($p \leq 0.012$), underscoring marked environmental gradients. Under high pressure, cultivar never differed (all $p \geq 0.137$), and block was likewise non-significant (all $p \geq 0.060$), suggesting that heavy initial infestations overwhelmed host-plant differences (Table 1).

Table 1. Analysis of variance for effects of cultivar and block on adult *Bemisia tabaci* per third fully expanded leaf during Weeks 1-4 under low, moderate, and high initial infestation.

Initial infestation condition	Week 1		Week 2		Week 3		Week 4	
	F	*p* > F	F	*p* > F	F	*p* > F	F	*p* > F
Low								
Whitefly count	2.1	0.091	2.4	0.056	5.0	<.001	8.7	<.001
Rep/ block	2.8	0.027	4.0	0.005	8.1	<.001	1.6	0.181
Moderate								
Whitefly count	3.0	0.023	1.4	0.236	2.6	0.042	0.6	0.640
Rep/ block	17.9	<.001	23.7	<.001	8.7	<.001	3.5	0.012
High								
Whitefly count	0.1	0.991	0.5	0.707	1.8	0.137	0.2	0.925
Rep/ block	0.7	0.614	2.4	0.060	1.1	0.386	0.8	0.516

Note: For all weeks, df for Whitefly count and Rep/block is 4. Residual (denominator) df by condition and week: Low = 116 (wk1–wk4); Moderate = 91, 91, 90, 71; High = 91, 91, 78, 68.

Mean (±SE) adult whiteflies per experimental leaf are summarized in Table 2. Under low pressure, cultivars did not differ in Weeks 1 and 2. Divergence appeared by Week 3 and was strongest by Week 4, when Husky Cherry (40.0 ± 10.2) and Better Boy (37.4 ± 7.61) formed the highest group, Roma was intermediate (7.8 ± 1.28), and Beefsteak (10.6 ± 2.97) and Sweet 100 (4.28 ± 0.85) remained lowest. Under moderate pressure, differences were transient: Husky Cherry was higher in Week 1 (30.4 ± 4.26), Better Boy was higher in Week 3 (37.6 ± 8.31), and Weeks 2 and 4 showed no significant differences. Despite strong block effects, cultivar means converged by Week 4. Under

high pressure, no cultivar separated in any week, consistent with nonsignificant omnibus tests. Nevertheless, all cultivars followed a similar rise-and-fall trajectory, with counts peaking at Week 3 (for example, Better Boy 65.1 ± 6.76) and declining by Week 4 (see Table 2 and Figures 1 to 3).

Temporal dynamics

Time-series plots (Figs. 1a-c) highlight how initial pressure modulated host effects. Under low pressure (Fig. 1a), Husky Cherry and Better Boy showed late acceleration, whereas Sweet 100 and Beefsteak stayed low, yielding clear separation by Week 4. Under moderate pressure (Fig. 1b), curves partially diverged mid-trial (Week 3) but reconverged by Week 4. Under high pressure (Fig. 1c), all cultivars shared the same rise-and-fall profile, indicating that heavy starting populations can mask cultivar differences over short time scales.

Table 2. Mean (±SE) adult *Bemisia tabaci* per third fully expanded leaf by tomato cultivar across Weeks 1–4 under each initial infestation level.

Tomato variety/ whitefly condition	Average ± SE whitefly adult count/third fully expanded leaf			
	Week 1	Week 2	Week 3	Week 4
Low initial infestation				
Husky Cherry	5.32 ± 1.09 a*	2.60 ± 0.51 a	9.56 ± 1.33 a	40.00 ± 10.20 b
Better Boy	3.68 ± 0.66 a	4.68 ± 1.03 a	18.60 ± 3.51 b	37.40 ± 7.61 b
Roma	4.36 ± 1.05 a	6.08 ± 1.55 a	12.50 ± 3.00 ab	7.80 ± 1.28 a
Beefsteak	2.56 ± 0.45 a	2.60 ± 0.42 a	7.24 ± 1.54 a	10.60 ± 2.97 a
Sweet 100	2.88 ± 0.57 a	3.44 ± 1.12 a	7.04 ± 1.66 a	4.28 ± 0.85 a
Moderate initial infestation				
Husky Cherry	30.40 ± 4.26 b	22.30 ± 3.26 a	28.80 ± 6.12 ab	31.60 ± 8.42 a
Better Boy	19.60 ± 4.15 ab	24.20 ± 4.31 a	37.60 ± 8.31 b	45.50 ± 11.40 a
Roma	22.70 ± 5.00 ab	22.00 ± 6.53 a	34.40 ± 8.40 ab	31.40 ± 6.95 a
Beefsteak	18.10 ± 2.92 a	15.90 ± 3.46 a	25.00 ± 6.39 ab	29.10 ± 8.24 a
Sweet 100	17.30 ± 3.64 a	15.00 ± 5.97 a	12.30 ± 4.95 a	25.60 ± 8.61 a
High initial infestation				
Husky Cherry	21.50 ± 2.33 a	46.60 ± 3.75 a	62.40 ± 7.01 a	15.70 ± 2.14 a
Better Boy	21.00 ± 2.79 a	46.60 ± 4.00 a	65.10 ± 6.76 a	15.60 ± 2.30 a
Roma	20.50 ± 2.65 a	44.80 ± 2.98 a	56.70 ± 5.21 a	17.10 ± 2.47 a
Beefsteak	19.80 ± 1.91 a	40.60 ± 3.25 a	42.40 ± 6.37 a	15.00 ± 2.57 a
Sweet 100	21.20 ± 2.29 a	43.80 ± 3.21 a	64.40 ± 7.15 a	18.20 ± 2.54 a

Note: Within each week x condition, means followed by the same letter are not different (Tukey HSD, α=0.05).

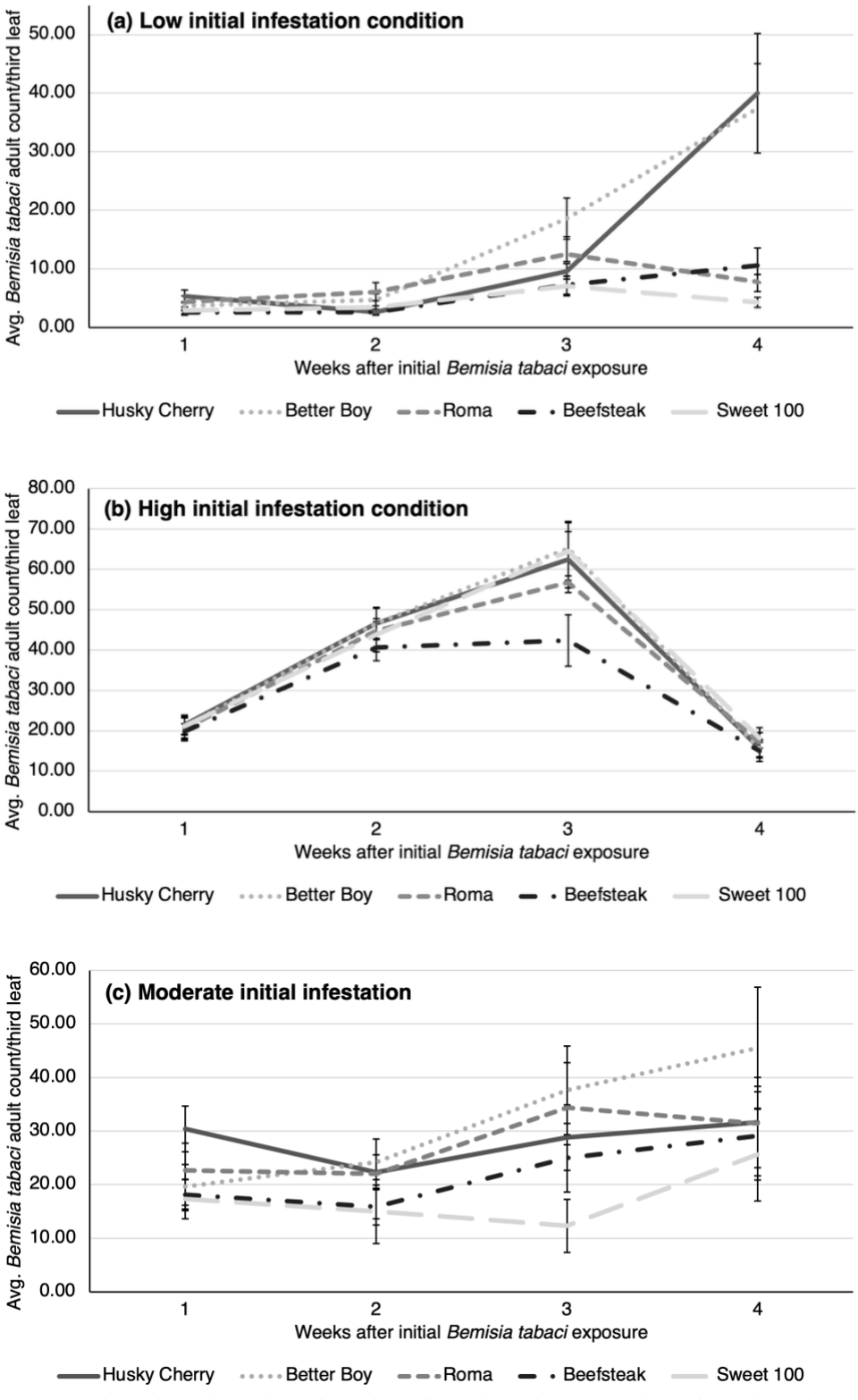

Figure 1. Weekly dynamics of sweetpotato whitefly on greenhouse tomato under (a) low, (b) moderate, and (c) high initial infestation levels.

Discussion

Cultivar effects on *Bemisia tabaci* adult abundance in greenhouse tomato are strongly contingent on starting pest pressure. In the current experiment, when initial infestation was low, cultivar means were indistinguishable in Weeks 1 and 2 but separated by Weeks 3 and 4. ‘Husky Cherry’ and ‘Better Boy’ formed the upper group, ‘Roma’ was intermediate, and ‘Beefsteak’ and ‘Sweet 100’ remained lowest. Under moderate pressure, separation was brief, with ‘Husky Cherry’ higher in Week 1 and ‘Better Boy’ higher in Week 3, followed by convergence in Week 4. Under high pressure, cultivars did not separate in any week, although all followed the same pulse of increase to Week 3 and decline by Week 4. Frequent and sometimes strong block effects indicated spatial heterogeneity typical of protected culture.

Two complementary mechanisms likely explain why host differences emerged only under favorable contexts. First, host plant resistance traits that deter settling or reduce performance require time and moderate density to influence population growth. Tomato resistance to *B. tabaci* has been linked to glandular trichomes and their metabolites, including acylsugars, methyl ketones, and terpenoids, which limit settling and fecundity and can slow population buildup (Bleeker et al., 2009; Firdaus et al., 2012; McDaniel et al., 2016; Perier et al., 2022). The delayed separation we observed at low pressure is therefore consistent with trait expression that influences cumulative settling rather than immediate knockdown. Second, plant-insect signaling interactions can attenuate or amplify resistance depending on density and time. Whitefly effectors can manipulate secondary metabolites, such as salicylic and jasmonic acid signaling, while resistant hosts can counter through phloem-based defenses and altered defense prioritization (Denkers et al., 2025). Cross talk between salicylic and jasmonic pathways can create antagonism that influences performance of phloem feeders such as whiteflies, which helps explain why small early differences can scale at low pressure but become masked when immigration and reproduction are high (Perier et al., 2022).

The lack of cultivar separation at high starting pressure likely reflects density-dependent masking. When many adults arrive or reproduce quickly, the cumulative effector load

and rapid reinfestation can swamp bottom-up resistance, a pattern consistent with the biology and invasion history of *B. tabaci* in warm and controlled production systems (Baldin et al., 2007; Li et al., 2021). The recurrent block effects we detected are also expected in protected culture where light, temperature, and airflow gradients alter local population growth and natural enemy activity even when treatments are randomized (Arnemann et al., 2019). These positional influences help explain the transient or absent cultivar separation under moderate and high pressure, respectively.

From a management perspective, our results indicate that cultivar choice is most informative when starting pressure is low. Under that condition, selecting lower-susceptibility entries such as ‘Sweet 100’ or ‘Beefsteak’, while monitoring ‘Husky Cherry’ and ‘Better Boy’ more closely, can delay buildup and reduce the need for interventions. As pressure increases to moderate or high, cultivar differences diminish and additional integrated tactics become necessary, including sanitation, exclusion screens, biological control, and judicious insecticide use within resistance-management frameworks (Baldin et al., 2007; Arnemann et al., 2019; Li et al., 2021; Souza et al., 2025). This hierarchy aligns with current thinking that host plant resistance should be combined with other IPM components rather than used in isolation.

In this study, we quantified adults on a standardized leaf, which is useful for tracking establishment but does not partition settling, oviposition, or nymphal survival. However, adding life-stage specific measures, virus transmission metrics, and direct assays of trichome density and chemistry would help identify resistance modality. Mapping microclimatic gradients within the greenhouse and explicitly manipulating immigration would clarify the relative roles of host traits versus positional effects. Finally, extending the panel to include cultivars with known HPR components, such as acylsugar and sesquiterpenoids, for example, could test whether chemical phenotype predicts rank order at low pressure.

Conclusion

Cultivar effects on *B. tabaci* adults in greenhouse tomato are detectable at low initial infestation, sporadic at moderate levels, and undetectable at high pressure. Current

literature on trichomes, plant signaling, and effector biology provides a coherent mechanistic basis for this pattern. Practically, producers should prioritize keeping starting pressure low through sanitation and exclusion, then leverage cultivar choice as a complementary lever. Once pressure is moderate to high, broader IPM must be engaged regardless of cultivar identity.

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