JOURNAL OF APPLIED ENTOMOLOGY

J. Appl. Entomol.

Evaluation of damage to satsuma mandarin (*Citrus unshiu*) by the leaffooted bug, *Leptoglossus zonatus* (Hemiptera: Coreidae)

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Keywords

damage estimation, feeding, *Leptoglossus zonatus*, satsuma mandarin

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Received: August 5, 2009; accepted: December 8, 2009.

doi: 10.1111/j.1439-0418.2009.01497.x

Abstract

The leaffooted bug, *Leptoglossus zonatus* (Dallas) (Hemiptera: Coreidae) is a key direct pest of satsuma mandarin (*Citrus unshiu* Marcovitch) in much of the Gulf Coast region of the United States. The injury and amount of damage to satsuma fruit caused by *L. zonatus* adults and nymphs at various insect densities (0–3 individuals per fruit) and feeding durations (0–14 days after infestation) were assessed in laboratory and field experiments. The parameters evaluated included fruit damage symptoms, fruit colour, premature fruit abortion (PFA), fruit weight loss (FWL), percentage of damaged sections (PDS), and soluble solids content (SSC) of the fruits. Feeding by *L. zonatus* on satsuma produced typical damage symptoms including the presence of green spots and dark spots on the outer rind and the collapsing and drying out of the juice vesicles in the inner rind. Insect density and feeding duration had significant effects on most damage parameters. Fruit weight loss and PDS increased with insect density and feeding duration. Soluble solids content decreased with both factors, and was also negatively correlated to PDS. Premature fruit ripening (yellowing) was recorded at densities of 1 or more insects per fruit. Premature fruit abortion was significantly higher in fruits infested by *L. zonatus* than in uninfested fruits, but insect density may not fully explain the PFA data. *Leptoglossus zonatus* female and male produced similar amounts of damage, which were slightly more than the damage produced by the nymphs. In general, the results were fairly consistent between laboratory and field experiments, although some minor differences were recorded. The data suggest an economic injury level of 1–2 *L. zonatus* per satsuma fruit. The results are discussed in relation to the ecology and management of *L. zonatus* on satsuma.

Introduction

Satsuma mandarin, *Citrus unshiu* Marcovitch, has been grown for over a century in the Gulf Coast region of the United States (English and Turnipseed 1940). However, the last decade has recorded a major increase in the production of this crop in southern Alabama, fuelled by improved production and tree protection methods and strong industry and state support (Campbell et al. 2004). Studies have identified several pest species capable of limiting the expansion of satsuma mandarin production in the region (Henne et al. 2003; Fadamiro et al. 2007, 2008). In particular, two species of leaffooted bugs (Hemiptera: Coreidae), *Leptoglossus zonatus* (Dallas) and *L. phyllopus* (L.), were identified as key direct pests of satsuma with the potential for major economic losses (Henne et al. 2003; Fadamiro et al. 2008). In southern Alabama, the predominant *Leptoglossus* spp. on satsuma is *L. zonatus* (Dallas), whereas *L. phyllopus* (L.) is considered a minor pest (Fadamiro et al. 2008). Recent surveys showed that *L. zonatus* is a widely distributed and perennial pest of satsuma in Alabama, which was recorded at high population densities in most of the surveyed orchards (Fadamiro et al. 2008).

Like many other *Leptoglossus* species, *L. zonatus* has recently risen in status as a pest of a wide range of crops in the southern U.S., including cotton, tomato, eggplant, sorghum, watermelons, corn, peaches, citrus, and pecans (Albrigo and Bullock 1977; Matrangolo and Waquil 1994; Johnson and Allain 1998; Schaefer and Panizzi 2000; Buss et al. 2005). In southern Alabama, *L. zonatus* adults typically move from crop fields (e.g., cotton, tomatoes, watermelons, etc.) into adjacent or nearby satsuma orchards in the fall when the fruits start to ripen (Y. F. Xiao and H. Y. Fadamiro, personal observation). A recent study by our group suggests that satsuma fruit is a suitable host for *L. zonatus*, which can maintain modest to high populations of the pest, but tomato is preferred over satsuma (Xiao and Fadamiro, 2009). Feeding on citrus fruit by leaffooted bugs nymphs and adults can result in reduction in quality and quantity of fruits, including premature colour break, fruit drop, and unmarketable fruit (Griffiths and Thompson 1957; Albrigo and Bullock 1977; Henne et al. 2003). The insects can also transmit yeast disease pathogen, *Nematocera coryli* Peglion, to fruit, which causes dryness in the affected wedges of the fruit and produces bad fruit flavour (Henne et al. 2003). However, several of the background information and data necessary for effective management of *L. zonatus* on satsuma are missing, including the absence of a systematic assessment of injury and economic thresholds for *L. zonatus* on satsuma. The objectives of this study were to (i) characterize interior and exterior damage symptoms on satsuma fruit caused by *L. zonatus*; (ii) determine relationship between insect density, feeding duration and fruit damage; and (iii) propose an economic injury level for *L. zonatus* on satsuma based on the data from the above laboratory and field studies. It is hoped that the results will support the development of an effective integrated pest management program for managing *L. zonatus* on satsuma mandarin.

Materials and Methods

Rearing of *Leptoglossus zonatus*

Adults of *L. zonatus* collected from satsuma orchards in southern Alabama in the fall of 2007 were used to start laboratory colonies. Adults were reared in wooden sleeve cages ($60 \times 40 \times 30$ cm; 5 pairs per cage) with screened walls, and provided lima bean seedlings (3 potted plants per cage), fresh mature satsuma fruits (3 per cage), fresh tomatoes (3 per cage) and water. The cages were checked daily to collect freshly laid eggs and to replace diet, as necessary. Lima bean seedlings were replaced monthly, whereas satsuma and tomato fruits were replaced biweekly and weekly, respectively. Satsuma fruits used were harvested from the field and stored in the refrigerator until use, while tomato fruits were purchased locally. The rearing conditions were 25 ± 2°C, 50 ± 10% RH, and a photoperiod of 14 : 10 (L : D) h.

Laboratory tests

Damage to satsuma fruit by *L. zonatus* was evaluated under laboratory conditions (25 ± 2°C, 50 ± 10% RH, and 14 : 10 (L : D) h during fall 2008. Fresh, mature satsuma fruits were weighed and placed individually into glass jars (18 cm long $\times$ 7.5 cm diameter, 1 fruit per jar). Newly-emerged *L. zonatus* females (2–5 days old) were introduced into each jar at one of four densities: 0 (control), 1, 2, or 3 per fruit. The jar was covered with screening nets. The set up consisted of a total of 48 jars distributed into four groups of 12 jars for each insect density. Each fruit was weighed at 1 (12 replications), 3 (12 replications), 7 (9 replications), 10 (6 replications), and 14 (3 replications) days after infestation. At 3, 7, 10, and 14 days after infestation, three fruits were selected from each group and dissected to determine interior damage. Fruit weight loss (FWL) was calculated by comparing weight before and after infestation. The percentage of damaged sections (PDS) was calculated for each fruit by dividing the number of damaged sections by the total number of sections (usually 10 sections). The soluble solids content (SSC) of the fruit was then measured with a refractometer (Westover Scientific model RHB-32ATC; Seattle, WA, USA). Similar experiments were performed with *L. zonatus* male and late (4th–5th) instars. Early instars (2nd–3rd) were not tested based on a preliminary experiment which showed that they produce very little measurable damage to satsuma.

Field tests

Field experiments were performed in two satsuma orchards located in Baldwin county, southern Alabama during 2007 (preliminary trial) and 2008: Gulf Coast Research and Extension Center (GCREC) orchard and Coker orchard. Both orchards were comprised mainly of satsuma mandarin (Owari variety) and were not conventionally sprayed during the trials. For the 2007 trial, three premature satsuma fruits on a tree branch were randomly selected and covered with a cage (35×15 cm diameter) made from white colour screening net. *Leptoglossus zonatus* females were placed into the cages at an approximate density of 0 (control), 0.3, 0.7, 1.4, or 2 individuals per fruit for a period of 14 days. Each insect density treatment was replicated four times (4 cages) per orchard. On day 15, the fruits were harvested (by hand) and carefully transported (in plastic bag kept in ice) to the laboratory where they were weighed and inspected for external and interior damage. A similar technique was used for the 2008 trial but with some modifications. Two premature fruits were caged (instead of 3 in 2007) and *L. zonatus* were placed in the cages at a density of 0, 0.5, 1, 2 or 3 individuals per fruit. Also both female and male were tested separately in 2008. Each insect density treatment was also replicated four times (4 cages) per orchard. In both years, fruits were assessed for damage by collecting the following data: fruit colour, premature fruit abortion (PFA), fresh fruit weight (FFW), PDS, and SSC.

Statistical analysis

For the laboratory test, FWL was calculated as the difference in fruit weight before and after infestation. Fruit weight loss data were converted to percentages and used in the statistical analyses. Data on damage fruit sections (PDS) and SSC were also expressed as percentages. All data were first normalized by using the arcsine square-root transformation ($\sqrt{x} + 0.5$). Laboratory data (FWL, PDS, and SSC) were first analyzed with two-way analysis of variance (ANOVA) with insect density and feeding duration (days after infestation) as the main factors. Data collected on day 14 after infestation were further analyzed with one-way ANOVA to test for effect of insect density on FWL, PDS and SSC. Field data (PFA, FFW, PDS, and SSC) collected from each orchard on day 15 after infestation were analyzed with one-way ANOVA using insect density as the independent variable. In all tests, data for the different stages (female, male or nymphs) were analyzed separately. Significant differences between means were established by using Tukey-Kramer honestly significant difference (HSD) comparison test ($P < 0.05$, JMP version 7.01, SAS Institute Inc. 2007).

Results

Description of fruit damage

Leptoglossus zonatus pierced satsuma fruit skin with its mouthparts and sucked fluids directly from the underlying vesicles. A 'green island' on outer rind (fig. 1a) and necrosis on inner rind (fig. 1b) often appeared on injured satsuma fruits. Dark spots were also observed on some injured fruits. Feeding may also result in interior fruit damage including collapsing and drying out of the juice vesicles (fig. 1c). Premature ripening (yellowing) of infested fruit was also observed in the field tests. There was no difference in the appearance of damage caused by all life stages of *L. zonatus*.

Laboratory tests

For *L. zonatus* female, two-way ANOVA revealed significant effects of insect density and feeding duration (days after infestation) on all three parameters evaluated: FWL, PDS, and SSC, as well as a significant density $\times$ duration interaction on PDS and SSC (table 1). Insect density and feeding duration each exerted a significant positive effect on FWL (fig. 2) and PDS (fig. 3), but a negative effect on SSC (fig. 3). In other words, FWL and PDS increased with increasing insect density and feeding duration, while SSC decreased with both factors. Similar results were obtained for *L. zonatus* male and nymphs. The statistics for both sexes and the nymphs are shown in table 1. For brevity, data obtained on day 14 of infestation (feeding duration of 14 days) were analyzed by one-way ANOVA and presented in table 2. In general, FWL and PDS increased with increasing insect density and feeding duration, while SSC decreased with both factors. For instance, FWL increased from 19.6% to 24.3% and PDS from 3% to 71%, whereas SSC decreased from 8.4% to 6.3% at densities of one female/fruit and three females/fruit, respectively (table 2). The data also indicated that slightly higher fruit damage (FWL and PDS) were caused by *L. zonatus* females or males than by the nymphs (fig. 3), although no statistical comparisons were made since the data for the different stages were not collected at the same time.

Field tests

Feeding by *L. zonatus* female or male caused notable damage to satsuma fruits as determined by fruit colour, PFA, FFW, PDS, and SSC. In the 2007 trial, only female were evaluated at both orchards.

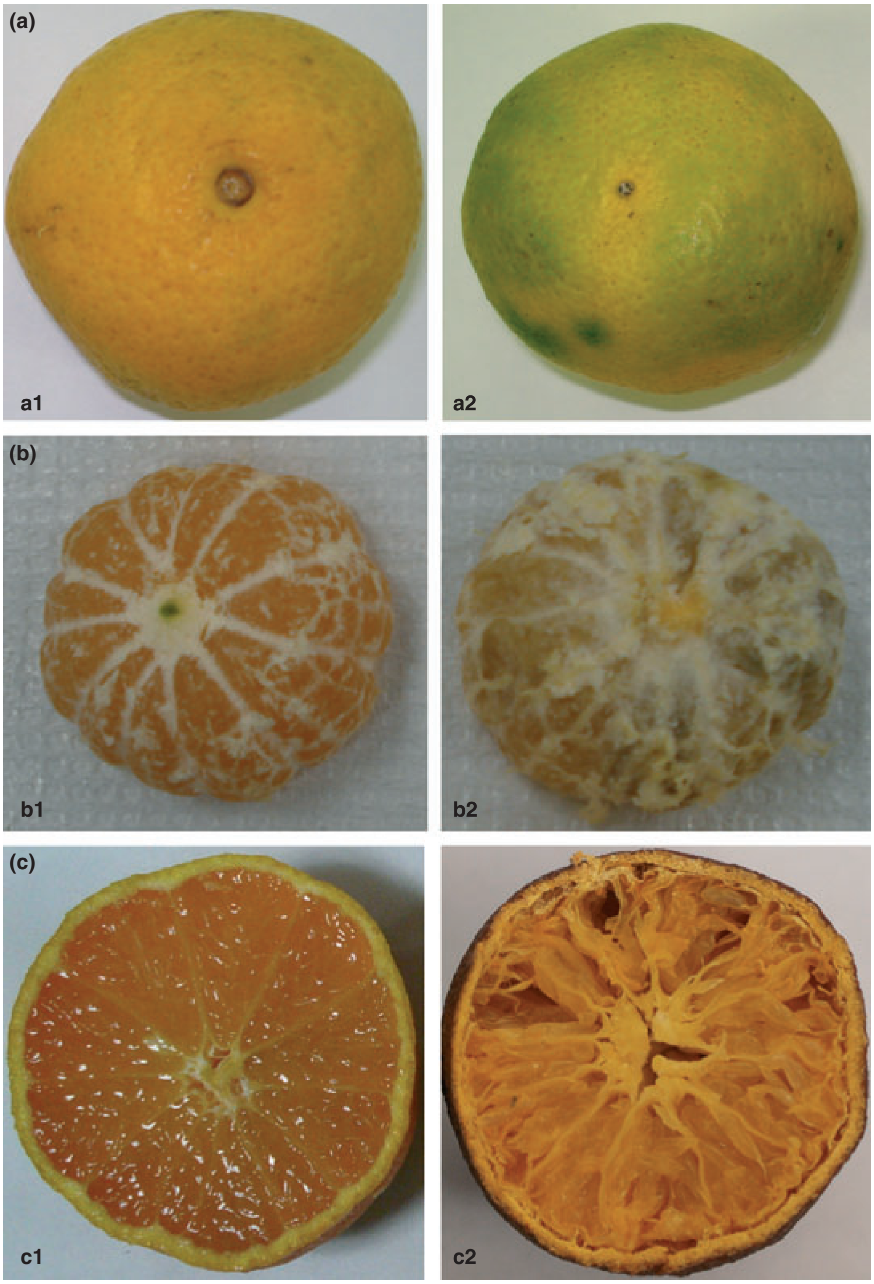

Fig. 1 Damage symptoms on satsuma fruits infested by *Leptoglossus zonatus*. (a) (external damage): control fruit showing no damage (a1), 'green islands' on outer rind of infested fruit (a2); (b) (necrosis): control fruit showing no necrosis (b1), necrosis on inner rind of infested fruit (b2); (c) (internal damage): control fruit showing no internal damage (c1), infested fruit showing dried-out juice sacs (c2).

Analysis of the data collected at Coker orchard showed that female density had a significant positive effect on PFA ($F = 23.3$; d.f. = 4, 55; $P < 0.0001$) and PDS ($F = 118.2$; d.f. = 4, 55; $P < 0.0001$), but a negative effect on FFW ($F = 19.6$; d.f. = 4, 55; $P < 0.0001$) and SSC ($F = 21.8$; d.f. = 4, 55; $P < 0.0001$). Similar results were obtained at GCREC orchard: insect density had a significant positive effect on PFA ($F = 33.4$; d.f. = 4, 55; $P < 0.0001$) and PDS ($F = 96.4$; d.f. = 4, 55; $P = 0.0001$) and a negative effect on FFW ($F = 3.33$; d.f. = 4, 55; $P = 0.01$) and SSC ($F = 96.3$; d.f. = 4, 55; $P = 0.001$). Premature fruit yellowing was recorded at densities of 0.7 or more insects per fruit. In 2008, both female and male were evaluated at the two orchards and the results were generally similar to those obtained in

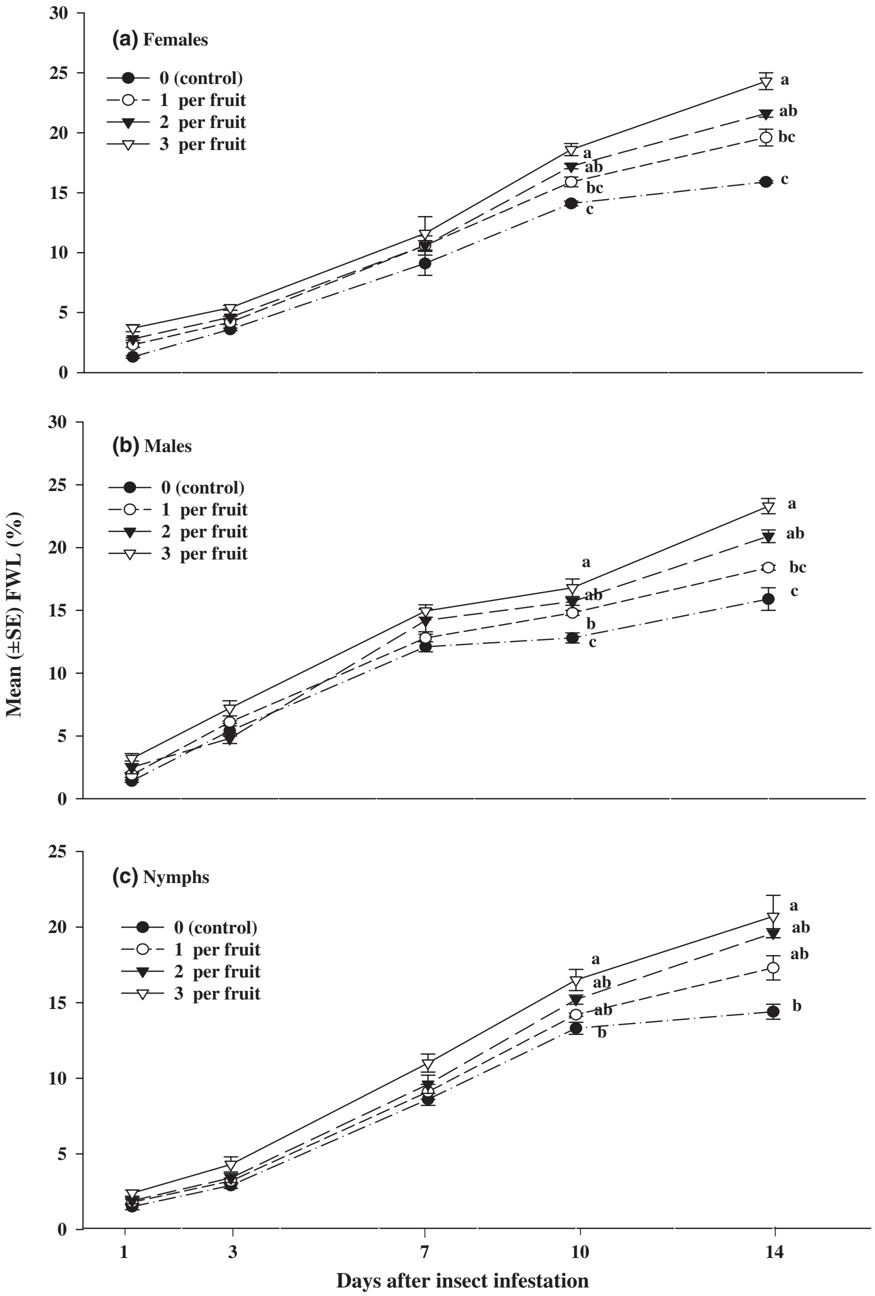

Fig. 2 Effects of insect density and feeding duration on percentage fruit weight loss (% FWL) of satsuma fruits infested by *Leptoglossus zonatus* in laboratory tests. (a) Females, (b) Males, (c) Nymphs. Figure shows mean (±SE) number of FWL (%) over different feeding periods.

2007. At both orchards, female density had a significant positive effect on PFA and PDS, but a negative effect SSC (table 3, fig. 4). Similar results were recorded also for male: increasing male density resulted in increased PFA and PDS and reduced SSC (table 4). An effect of insect density on fruit colour was also recorded at both locations and for both sexes. Premature fruit yellowing was recorded at densities of 1 or more insects per fruit, whereas fruits caged with ≤1 insects per fruit were still mainly green 14 days after infestation. However, no significant effect of insect density on FFW was recorded in 2008 (tables 3 and 4). In general, no significant differences were recorded between the densities of 0 (control) and 0.5 insect per fruit for most damage parameters.

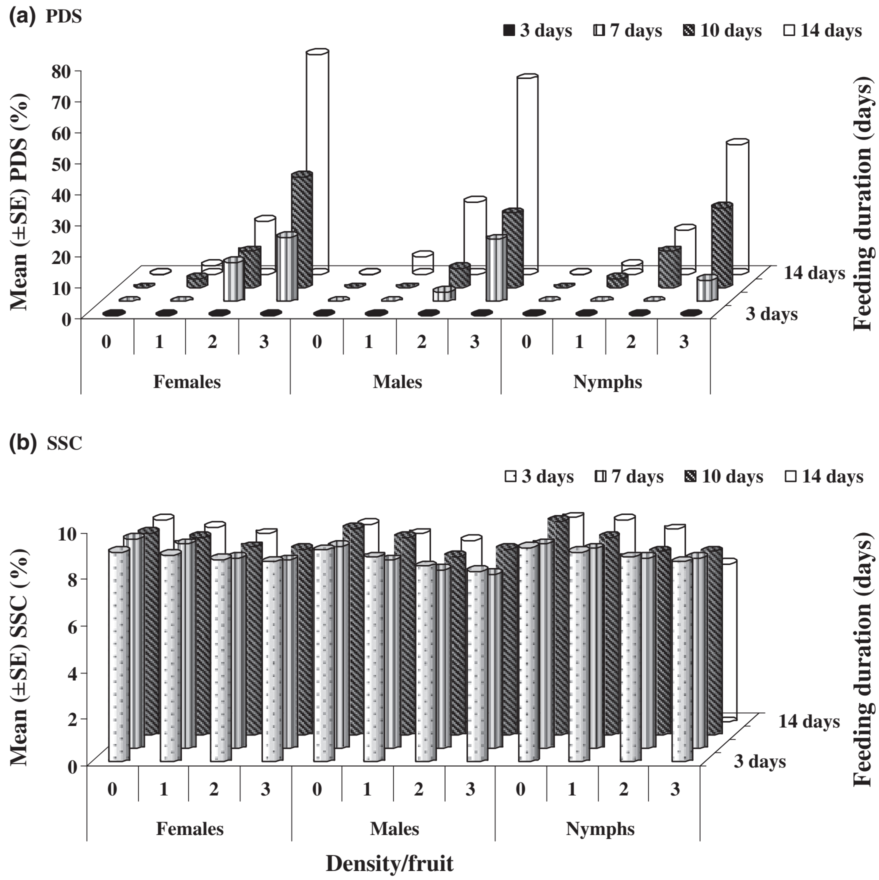

Fig. 3 Effects of insect density and feeding duration on (a) percentage damaged sections (PDS) and (b) soluble solids content (SSC) of satsuma fruits infested by *Leptoglossus zonatus* in laboratory tests.

Table 1 Two-way ANOVA testing for effects of insect density, feeding duration, and interactions of both factors on fruit weight loss (FWL), percent damaged sections (PDS), and soluble solids content (SSC) of satsuma fruits infested by *Leptoglossus zonatus* in laboratory tests

			Female		Male		Nymphs	
	Effect	d.f.	F	P	F	P	F	P
FWL	Density	3	74.8	0.0001	37.1	0.0001	16.4	0.0001
	Duration	4	1424.8	0.0001	738.0	0.0001	599.0	0.0001
	Density × duration	12	2.8	0.0016	1.6	0.112	0.6	0.84
PDS	Density	3	166.7	0.0001	62.9	0.0001	59.7	0.0001
	Duration	3	70.9	0.0001	39.0	0.0001	42.6	0.0001
	Density × duration	9	35.1	0.0001	12.9	0.0001	14.2	0.0001
SSC	Density	3	7.4	0.0007	18.2	0.0001	25.7	0.0001
	Duration	3	4.9	0.006	9.1	0.0002	10.8	0.0001
	Density × duration	9	1.4	0.217	1.2	0.34	4.1	0.001

FWL, fruit weight loss; PDS, percent damaged section; SSC, soluble solids content.

Four levels of insect density (0, 1, 2 or 3 per fruit) were evaluated at feeding durations of 1, 3, 7, 10, and 14 days after infestation for FWL and at 3, 7, 10 and 14 days after infestation for PDS and SSC.

Discussion

The symptoms of *L. zonatus* feeding damage on satsuma fruit recorded in this study have been previously reported on satsuma or other citrus species (Ebeling 1950; Griffiths and Thompson 1957; Albrigo and Bullock 1977; Kubo and Filho 1992; Henne et al. 2003; Buss et al. 2005). Henne et al.

Table 2 Effect of insect density on fruit weight loss (FWL), percent damaged section (PDS), and soluble solids content (SSC) of satsuma fruits infested by *Leptoglossus zonatus* for 14 days in laboratory tests

		Mean (±SE) per fruit		
Stage	Density (no. per fruit)	FWL (%)	PDS (%)	SSC (%)
Female	0.0	15.9 ± 0.3 c	0 c	8.7 ± 0.2 a
	1.0	19.6 ± 1.2 bc	3.0 ± 3.0 c	8.4 ± 0.2 a
	2.0	21.6 ± 0.5 ab	17.2 ± 0.5 b	8.1 ± 0.2 a
	3.0	24.3 ± 1.3 a	71.1 ± 4.4 a	6.3 ± 0.7 b
		$F = 13.84$	$F = 98.32$	≤ $F = 2.86$
		$P = 0.0015$	$P = 0.0001$	$P = 0.104$
Male	0.0	15.9 ± 1.5 c	0 c	8.5 ± 0.1 a
	1.0	18.4 ± 0.4 bc	5.8 ± 2.9 bc	8.1 ± 0.1 ab
	2.0	20.9 ± 0.9 ab	23.3 ± 6.7 b	7.8 ± 0.1 ab
	3.0	23.3 ± 1.1 a	63.1 ± 6.8 a	6.7 ± 0.6 b
		≤ $F = 9.4$	$F = 31.04$	$F = 4.8$
		$P = 0.005$	$P = 0.0001$	$P = 0.032$
Nymphs	0.0	14.4 ± 1.1 b	0 c	8.8 ± 0.2 a
	1.0	17.3 ± 1.4 ab	3.0 ± 1.5 bc	8.7 ± 0.2 a
	2.0	19.6 ± 0.6 ab	14.4 ± 3.1 b	8.3 ± 0.2 a
	3.0	20.7 ± 1.3 a	42.1 ± 4.1 a	6.8 ± 0.4 b
		≤ $F = 5.71$	$F = 39.11$	$F = 12.36$
		$P = 0.021$	$P = 0.001$	$P = 0.002$

FWL, fruit weight loss; PDS, percent damaged section; SSC, soluble solids content.
Mean (±SE) within the same column for each stage followed by different letters are significantly different ($P < 0.05$, Tukey-Kramer HSD test; d.f. = 3, 8).

Table 3 Evaluation of damage to satsuma fruit infested by *Leptoglossus zonatus* female in two south Alabama satsuma orchards in 2008

		Mean (±SE) per fruit				
Location	Density (no. per fruit)	Fruit colour	PFA (%)	FFW (g)	PDS (%)	SSC (%)
Coker	0	G	0 b	103.9 ± 3.5	0 d	9.1 ± 0.2 a
	0.5	G	0 b	85.7 ± 3.1	3.6 ± 1.8 d	8.7 ± 0.2 a
	1	Y	87.5 ± 12.5 a	97.8 ± 8.3	15.2 ± 2.3 c	8.2 ± 0.2 a
	2	Y	75.0 ± 16.2 a	88.3 ± 7.7	31.9 ± 3.9 b	6.0 ± 0.4 b
	3	Y	100 ± 0 a	80.8 ± 7.5	56.8 ± 6.8 a	5.0 ± 0.2 bc
			$F = 28.0$	≤ $F = 2.14$	≤ $F = 41.34$	$F = 45.99$
			$P < 0.0001$	$P = 0.09$	$P < 0.0001$	$P < 0.0001$
GCREC	0	G	0 c	113.2 ± 6.7	0 d	9.4 ± 0.3 a
	0.5	G	12.5 ± 6.5 bc	105.7 ± 3.9	3.0 ± 1.7 cd	8.6 ± 0.3 a
	1	Y	75.0 ± 16 ab	102.3 ± 1.3	11.0 ± 2.7 c	7.1 ± 0.2 b
	2	Y	62.5 ± 18.2 a	106.7 ± 6.8	37.0 ± 2.4 b	5.8 ± 0.3 c
	3	Y	100 ± 0.0 a	108.3 ± 6.0	71.0 ± 3.2 a	5.1 ± 0.3 c
			$F = 11.8$	$F = 0.512$	$F = 122.38$	$F = 39.99$
			$P < 0.0001$	$P = 0.691$	$P < 0.0001$	$P < 0.0001$

GGREC, Gulf Coast Research and Extension Center, Fairhope, AL; G, green colour; Y, yellow colour; PFA, premature fruit abortion; FFW, fresh fruit weight; PDS, damaged fruit sections; SSC, soluble solids content.
Mean (±SE) within the same column for each location followed by different letters are significantly different ($P < 0.05$, Tukey-Kramer HSD test; d.f. = 4, 35).

(2003) reported external damage to the rind of satsuma fruit infested by *L. zonatus,* in the form of green spots that remain for a time after the rind has turned orange. *Leptoglossus* spp. have also been reported to cause similar damage to other crops (Hall and Teetes 1982; Wheeler and Miller 1990; Grimm

Table 4 Evaluation of damage to satsuma fruit infested by *Leptoglossus zonatus* male in two south Alabama satsuma orchards in 2008

		Mean (±SE) per fruit				
Location	Density (no. per fruit)	Fruit colour	PFA (%)	FFW (g)	PDS (%)	SSC (%)
Coker	0	G	0 c	100.7 ± 4.3	0 d	9.5 ± 0.3 a
	0.5	G	0 c	90.8 ± 2.3	2.1 ± 1.4 d	8.6 ± 0.1 a
	1	Y	37.5 ± 18.2 bc	90.8 ± 4.5	17.2 ± 4.5 c	6.8 ± 0.5 b
	2	Y	50.0 ± 18.9 b	94.9 ± 4.8	34.3 ± 2.3 b	6.3 ± 0.4 b
	3	Y	100 ± 0.0 a	104.5 ± 3.9	64.8 ± 2.7 a	5.3 ± 0.5 b
			F = *12.4*	F = *2.36*	F = *99.37*	F = *18.37*
			P < *0.0001*	P = *0.07*	P < *0.0001*	P < *0.0001*
GCREC	0	G	0 c	101.0 ± 2.1	0 c	8.9 ± 0.3 a
	0.5	G	0 c	99.8 ± 1.9	1.4 ± 0.7 c	8.4 ± 0.2 a
	1	Y	50.0 ± 18.8 b	100.7 ± 2.2	8.1 ± 2.6 c	6.9 ± 0.3 b
	2	Y	87.5 ± 12.5 ab	100.9 ± 3.6	34.5 ± 4.1 b	6.9 ± 0.5 b
	3	Y	100 ± 0.0 a	91.6 ± 3.1	65.9 ± 4.1 a	5.0 ± 0.3 c
			F = *21.6*	F = *2.34*	F = *89.13*	F = *27.12*
			P < *0.0001*	P = *0.09*	P < *0.0001*	P < *0.0001*

GGREC, Gulf Coast Research and Extension Center, Fairhope, AL; G, green colour; Y, yellow colour; PFA, premature fruit abortion; FFW, fresh fruit weight; damaged fruit sections; SSC, soluble solids content.
Mean (±SE) within the same column for each location followed by different letters are significantly different (P < 0.05, Tukey-Kramer HSD test; d.f. = 4, 35).

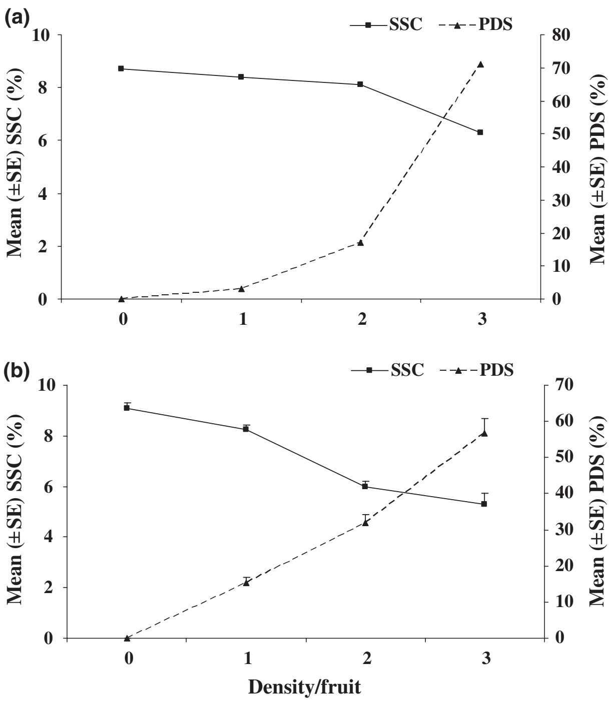

Fig. 4 Negative correlation between soluble solids content (SSC) and percentage damaged sections (PDS) of satsuma fruits infested by *Leptoglossus zonatus* female at different densities. (a) Data from the laboratory test, (b) Data from the field trial in Coker orchard in 2008.

1999). The premature abortion of *L. zonatus*-infested fruit recorded in our field tests has also been documented in other citrus species (Griffiths and Thompson 1957; Albrigo and Bullock 1977), as well as in other crops (Ebeling 1950; Wiseman and McMillian 1971; DeBarr and Kormanik 1975; Bolkan et al. 1984; Grimm 1999). DeBarr and Kormanik (1975) reported that *L. corculus* (Say) nymphs fed on the cytoplasm of cells of the nucellar tissue of pine conelets resulting in total conelet abortion after 4 days of feeding. Albrigo and Bullock (1977) suggested that citrus fruit drop from leaffooted bug feeding may be due to secondary infections by microorganisms. However, this hypothesis was not tested in the present study.

In addition to direct feeding injury, *L. zonatus* and other related species have also been reported to transmit the yeast, *Nematospora coryli*, which causes further fruit damage including drying rot (Clarke and Wilde 1970; Henne et al. 2003). Henne et al. (2003) attributed the collapsing and drying out of the juice sacs inside the rind of satsuma fruit infested by *L. zonatus* to this yeast. Although, we did not attempt to isolate this pathogen and other microorganisms, it is possible that some of the symptoms of internal fruit damage observed in this study were due to yeast or similar pathogens.

As expected, our results showed major effects of *L. zonatus* density and feeding duration on most fruit damage parameters. In general, higher insect density and longer feeding duration resulted in increased FWL and PDS, but lower SSC. The results were fairly consistent between laboratory and field experiments although minor differences were recorded. This is the first systematic evaluation of damage by *L. zonatus* or related species to satsuma or other citrus species. Similar results have been reported for some non-citrus crops damaged by *Leptoglossus* spp. (Hall and Teetes 1982; Grimm 1999). Hall and Teetes (1982) attributed the significant reduction in the yield of sorghum infested by *L. phyllopus* to direct seed feeding. Similarly, physic nut damaged by *L. zonatus* also showed a significant reduction in fruit weight and a slight reduction in oil contents (Grimm 1999).

We were not surprised to find a negative correlation between the PDS and SSC of satsuma fruit infested by *L. zonatus*. The SSC is commonly used as a measure of fruit juice quality (Widodo et al. 1996). Our data showed that a significant decline in SSC was not always recorded at densities lower than 2 individuals per fruit, suggesting that this parameter may not be a very good measure of *L. zonatus* feeding damage on satsuma. Also, SSC declined faster in the field trials than in the laboratory tests. For instance, the decrease in SSC was significant at the density of 1–2 individuals per fruit in the field trials but a significant decrease in SSC was not recorded in the laboratory tests below the density of 3 individuals per fruit. These differences may be related to the hotter and unstable field conditions. In general, *L. zonatus* female and male produced similar amounts of damage, which were slightly more than the damage produced by the nymphs. Grimm (1999) reported a similar finding on physic nut: *L. zonatus* adults of both sexes produced more damage than the nymphs.

One of the objectives of this study was to extrapolate the fruit damage data to possibly propose an economic threshold for *L. zonatus* on satsuma. *Leptoglossus zonatus* feeding affected fruit weight, yield, and quality, but the data showed that not all feeding resulted in significant measurable damage. For example, compared to uninfested (control) fruits, a significant FWL was not recorded below the density of 1 individual per fruit or at feeding durations of <10 days. Hall and Teetes (1982) reported a similar result on sorghum and concluded that two adults of *L. phyllopus* were generally not enough to cause significant reduction in the yield of green sorghum. Data from the laboratory tests showed that FWL and PDS values of uninfested control fruits were not significantly different from values for fruits infested by *L. zonatus* at a density of one individual per fruit, but significantly different from values for fruits infested at a density of two or more individuals per fruit. In contrast, PDS and PFA were significantly greater at the density of one individual per fruit compared to the control. We also observed premature ripening of infested fruit at densities of 1 or more individuals per fruit. Similar results on PFA were reported for pistachio fruits infested by *L. clypealis* L., which resulted in an increase in PFA from 3.8% in the control to 32.9% in fruit clusters fed upon for 48 h by a single *L. clypealis* (Bolkan et al. 1984). However, Grimm (1999) cautioned against reliance on PFA to diagnose economic damage by bugs, since fruit abortion may be caused by other factors which are unrelated to insect feeding. For instance, Umaña and Carballo (1995) reported that only 33–49% of aborted macadamia nuts showed symptoms of bug feeding damage. Thus, our data on PFA may not be used as a reliable indicator of economic damage by *L. zonatus*. In general, our field results corroborated our laboratory data. The minor differences between our laboratory and field results may be related to differences in environmental conditions, as well as the impact of other field factors. Altogether, our data suggest an economic injury level (lowest insect density that will result in economic damage) of 1–2 *L. zonatus* per satsuma fruit. Although data collected from studies in which insects were confined on fruit may not necessarily provide an accurate estimation of fruit damage in the field because insects are not confined in nature, we consider our data on *L. zonatus* reliable given our field observation that adults and nymphs can stay continuously on a host tree or fruit for several hours to days. At present, it is difficult to accurately propose an economic or action threshold (insect density that will trigger control measures to prevent the density from reaching economic injury level) for *L. zonatus* on satsuma, due to several factors including lack of effective monitoring and sampling techniques and the inability to accurately predict its movement from adjacent crop fields into satsuma orchards. Knowledge of these factors and the economics of managing *L. zonatus* will aid the development of a practical economic threshold for the pest on satsuma mandarin.

Acknowledgements

We thank Mr. Monte Nesbitt for helping with field collection of leaffooted bugs used in starting our laboratory colonies. Funding for this study was provided by the Alabama Agricultural Experiment Station and Auburn University Horticulture Line Item grants program.

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