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Evaluation of augmentative releases of *Franklinothrips orizabensis* for control of *Scirtothrips perseae* in California avocado orchards

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Abstract

The efficacy of augmentative releases of a predatory thrips, *Franklinothrips orizabensis*, was assessed for control of avocado thrips, *Scirtothrips perseae*. *F. orizabensis* were released weekly at a rate of 50 pupae per tree into replicated experimental blocks in two different 'Hass' avocado orchards in southern California, USA. Thrips-days calculated from weekly population counts and yellow sticky card monitoring were used to compare *S. perseae* and *F. orizabensis* densities in release and non-release (control) blocks. Augmentative releases of this predator failed to demonstrate an ability to control low densities (<5 *S. perseae* larvae per leaf) on small avocado trees (<3 m in height) and medium sized trees (4–5 m in height). Average field emergence rates of predators from deployed pupae ranged from 67 to 83% and sex ratio of emerged predators was male biased ranging 53–71%. Significant differences in emergence rates and sex ratio of predators were detected between sites and insectaries. Field longevity of predators was significantly affected by sex and the amount of food available. Male and female predators died quickly (accumulation of 14–23 day-degrees) when food was either absent or present in low quantities. Consequently, pre-emptive releases of mass-reared *F. orizabensis* to control low densities of *S. perseae* in avocado orchards in southern California in anticipation of pest outbreaks are not recommended.
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1. Introduction

Scirtothrips perseae Nakahara (Thysanoptera: Thripidae) emerged as a significant pest of California (USA) grown avocados in 1996 (Hoddle et al., 2002a). Feeding damage to immature fruits by larvae and adults in late spring and early summer has cost the California avocado industry millions of dollars in lost revenues each year (Hoddle et al., 2003). This pest is native to Mexico and Guatemala (Hoddle et al., 2002b), and most likely arrived in California on smuggled avocado plants, as *S. perseae* preferentially feeds and oviposits in the undersides of young leaves, and immature fruits less than 55 mm in length (Hoddle, 2002b). Population

growth and subsequent outbreaks are favored by moderate temperatures that coincide with leaf flush and fruit initiation in avocados (Hoddle, 2002a). An economic injury level of around five thrips per leaf is used to trigger pesticide applications at or just before fruit initiation to minimize *S. perseae* feeding damage to immature fruits (Hoddle et al., 2002a).

The key predator of *S. perseae* in California avocado orchards is the native thrips, *Franklinothrips orizabensis* Johansen (Thysanoptera: Aeolothripidae). Populations of this predator typically build in response to *S. perseae* outbreaks too late in the season to affect control before fruit damage occurs. *F. orizabensis* is a generalist predator that feeds on a variety of arthropods and can sustain itself for short periods on avocado pollen in the absence of prey (Hoddle et al., 2001a). This predator attacks first and second instar *S. perseae* at equal rates (Hoddle, 2003a), and foraging success is affected by the

complexity of the environment that is being searched (Hoddle, 2003b). Research on temperature (Hoddle et al., 2000), dietary requirements (Hoddle et al., 2001a), and pupation biology (Hoddle et al., 2001b) of this predator has enabled commercial California insectaries to mass-rear and harvest *F. orizabensis*.

In an attempt to reduce grower reliance on insecticides for *S. perseae* control and to delay or avoid pesticide resistance development, research into biological control agents to suppress *S. perseae* populations has been endorsed by California avocado growers. One biological control strategy that has been proposed is early season releases of mass-reared *F. orizabensis* to augment resident predator populations in avocado orchards in advance of *S. perseae* outbreaks. The motivation for evaluating augmentative releases of *F. orizabensis* has been to determine the feasibility of reducing or eliminating the early season lag period in predator population growth in response to increasing pest densities (Hoddle et al., 2001b, 2002a). The work presented here reports on the release efficacy of mass-reared *F. orizabensis* evaluated for the augmentative biological control of *S. perseae* in two commercial avocado orchards in southern California.

2. Materials and methods

2.1. Study sites and experimental set up

Two study sites were used for evaluating the efficacy of *F. orizabensis* releases for controlling *S. perseae*. Insecticides for control of *S. perseae* were not applied at either study site during the course of these evaluations. Both sites consisted of "Hass" avocados and were subjected to commercial watering, fertilizing, and soil amendment practices. Site one was a 6.5 ha orchard in San Marcos, San Diego County, California and consisted of 15-year-old trees that had been top-worked (i.e., trees were cut back and left to re-sprout from the scion) two years before the trial began. Trees in a 2.5 ha block of the orchard that were approximately 4–5 m tall and flushing heavily with new leaves were selected. Within this block, 12 experimental blocks (six predator release and six non-release [control]) of 5 trees each were selected to give similar mean starting densities of *S. perseae* across treatments. The trial at site one commenced July 17, 2001 and ended June 5, 2002.

Site two was in Camarillo, Ventura County, California and consisted of 82 ha from which 2–3 year old trees 1.5–2 m in height in a 2 ha block were selected. Within this block, 10 experimental blocks (five release and five non-release) of 5 trees each were selected to give similar starting densities of *S. perseae* across treatments. The trial at site two commenced June 26, 2001 and ended June 27, 2002.

For both sites, groups of experimental trees were immediately adjacent each other and in the same row. All experimental blocks were separated by a minimum of two buffer rows. Temperature and humidity at both study sites were recorded every 30 min with Hobo dataloggers (Onset Computer, Pocasset Massachusetts, USA) attached to stakes 1.5 m above the ground and positioned in the center of the study plot.

2.2. Sources of Franklinothrips orizabensis, quality control and sex ratio estimates

Two commercial California insectaries mass-reared *F. orizabensis* for use in this trial; one insectary was situated in Escondido (San Diego County and referred to as Insectary A) the other was located in Santa Paula (Ventura County and referred to as Insectary B). Each week, the insectaries provided *F. orizabensis* pupae harvested in plastic tubes for release at both sites. The majority of *F. orizabensis* released at site one were mass reared at the University of California at Riverside (UCR) and supplemented with material from Insectary A for the first 23 weeks. At site two, material from Insectary B was supplemented with material from Insectary A for the first 11 weeks. The intended weekly release rate at both study sites was 50 *F. orizabensis* pupae per tree. This high release rate of *F. orizabensis* was evaluated to determine if augmentative releases had the possibility of controlling *S. perseae*, and should control be observed, this release rate would act as a starting point for evaluating lower release rates in future trials. We estimated that the cost per hectare was approximately twice what a grower would pay for aerial applications of insecticides for *S. perseae* control.

Harvested pupae in plastic tubes were pre-counted and deployed in plastic vials with drainage holes that were attached with twist ties to branches within the canopy of experimental trees. Tubes with pupae were left in tree canopies for 1–2 weeks before being collected and returned to the laboratory where emergence rates under field conditions were determined. Sex ratio estimates were determined weekly in the laboratory by retaining 30–50 pupae in tubes from release batches. Retained pupae were inspected daily and emergence rates and sex of emerged predators were recorded.

2.3. Sampling protocols

2.3.1. Scirtothrips perseae and Franklinothrips orizabensis

At each study site for each week of the trial, the undersides of 10 randomly selected immature leaves (i.e., 3/4 expanded and either bronze or light green in color) on each of the five trees in each experimental block were inspected and the number of *S. perseae* larvae per leaf was recorded. Due to the agility and rarity of

F. orizabensis in avocado orchards, the most effective way of sampling this predator for density estimates was through the use of beat trays. Experimental trees were divided into quadrants and 1–2 branches in each quadrant were beaten 2–4 times against a white plastic tray (18 cm × 38 cm). The numbers of larval and adult *F. orizabensis* on beat trays were recorded per quadrant per tree sampled. Predators were then released back onto sampled trees.

2.3.2. Sticky card monitoring

Thrips movement between experimental blocks was monitored using yellow sticky cards, a color attractive to both *S. perseae* and *F. orizabensis* (Hoddle et al., 2002c). Cards were attached with clips to wooden stakes 1.5 m above the ground and situated between rows immediately adjacent to blocks of experimental trees. Sticky cards were designated as release or control depending on the adjacent block. Cards were replaced weekly, and in the laboratory, the numbers of adult *S. perseae* and *F. orizabensis* captured per card were recorded by cardinal direction and experimental block.

2.4. Field survivorship estimates

The longevity of *F. orizabensis* males and females provisioned with varying amounts of food, to mimic varying prey densities, was determined under field conditions by placing male–female pairs in ventilated plastic vials that were attached to branches within canopies of avocado trees. To quantify longevity, predators <24 h of age were used and 20 experimental pairs for each of six treatments were set up simultaneously. Predator pairs were randomly assigned to one of six treatments that were randomly assigned to branches in the canopies of one of 10 avocado trees. The six treatments were: (1) no food; (2) predators provisioned with an immature avocado leaf; (3) predators caged with 5% food (0.025 g of commercially purchased irradiated *Ephestia kuehniella* Zeller eggs [Lepidoptera: Pyralidae]); (4) 25% food (0.125 g of *E. kuehniella* eggs); (5) 50% food (0.25 g of *E. kuehniella* eggs); and (6) 100% food (0.5 g of *E. kuehniella* eggs, an amount of food known to be adequate to support adult *F. orizabensis* until death). Each predator pair was examined daily and longevity by treatment and sex was recorded. Temperature in tree canopies was recorded every 15 min with Hobo dataloggers and daily maximum and minimum temperatures were used for day-degree calculations. This study ran from March 14, 2002 to April 2, 2002, inclusive.

2.5. Data analysis

2.5.1. Population trends and thrips-days calculations

Weekly population counts were used to determine the mean number of *S. perseae* larvae per leaf for each ex-

perimental treatment and the total number of *F. orizabensis* counted from beat tray sampling per tree per sampling interval was determined for release and non-release plots. Thrips-days for *S. perseae* and *F. orizabensis* in release and non-release plots were calculated for each experimental block using geometric summation to estimate the area under the population curves. Total thrips-days per experimental block were calculated as the sum of products of the number of individuals at each sampling date and the time interval between sampling dates (Carey, 1993). Thrips-days were averaged across blocks for each treatment for either *S. perseae* or *F. orizabensis* and compared using Student's *t* test at the 0.05 level of significance (SAS, 1990).

2.5.2. Quality control

Proportion emergence data and proportion of emerged females were square root and arc-sine transformed and used for statistical comparisons. Laboratory and field emergence and sex ratio data for field sites one and two were compared using three-way ANOVA. Field site, source of predators and month of deployment were used a factors and the significance of interaction terms was set at the 0.05 level. Tukey's Studentized Range Test was used for means separation where significant interaction terms existed (SAS, 1990).

2.5.3. Field survivorship rates

Survival times for *F. orizabensis* were analyzed using two-way ANOVA at the 0.05 level of significance with treatment and predator sex as factors (SAS, 1990). Data for adult *F. orizabensis* longevity from Hoddle et al. (2000) were used to determine the lower temperature threshold (10.28 °C) used in calculating degree-day accumulations from recorded temperature data in tree canopies using the single sine method (UC-IPM, 2003). No upper temperature thresholds were specified for degree-day accumulation because these data are unavailable. The relationship between degree-day accumulation and proportion surviving within a treatment was described using a Weibull function of the form $y = 100e - (x/a)^b$. This function was fitted using nonlinear regression in SAS (1990) and used to estimate the degree-day accumulation for median survival times (50% survivorship) for each sex across treatments.

3. Results

3.1. Population trends and thrips-days calculations

At site one, *S. perseae* populations for both treatments dropped immediately after the trial commenced and was correlated with the onset of hot summer weather (Fig. 1A), a factor known to adversely affect *S. perseae* populations (Hoddle et al., 2002a). Similarly,
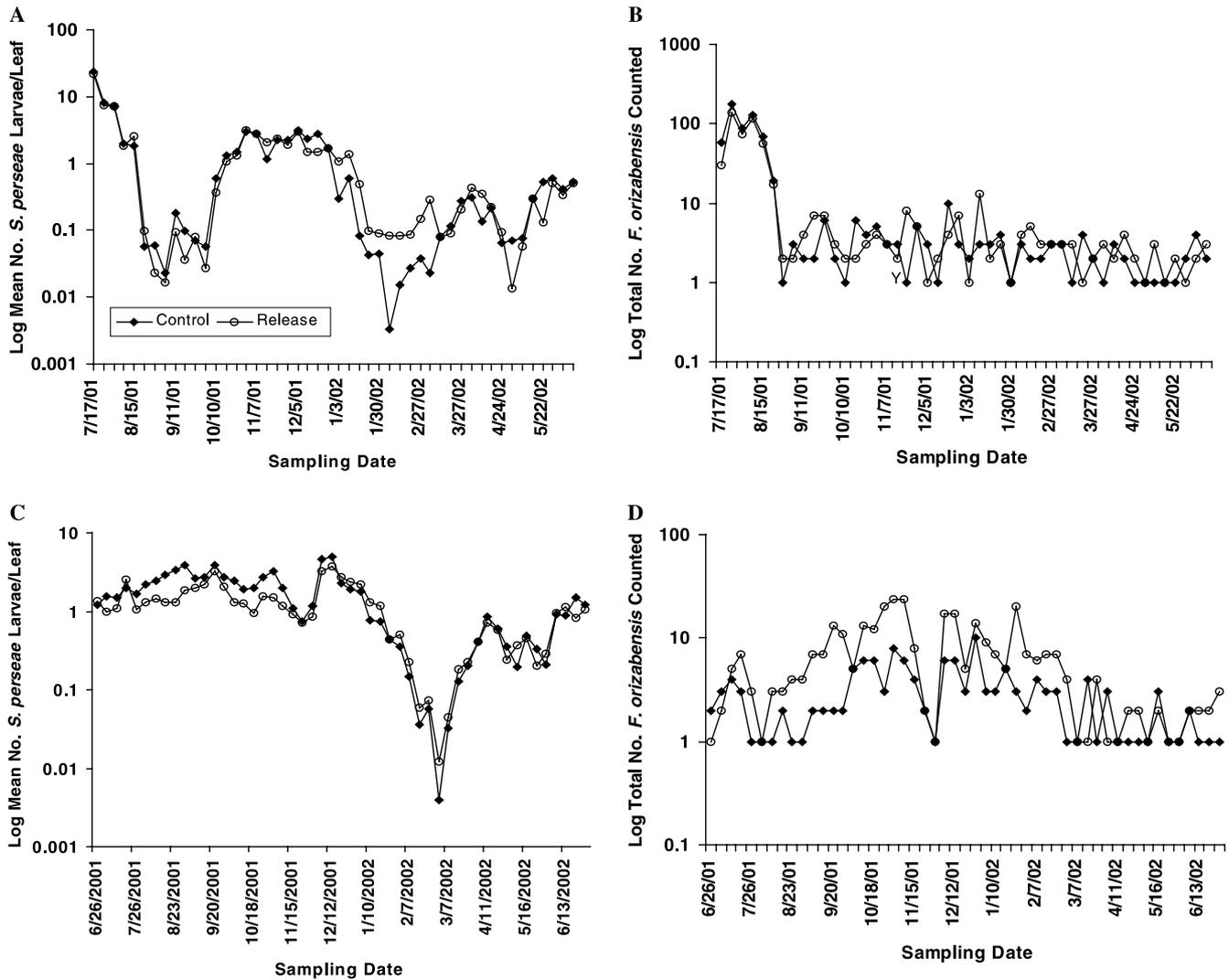
Fig. 1. Population trends for *S. perseae* (A) and *F. orizabensis* (B) at site one and for *S. perseae* (C) and *F. orizabensis* (D) at site 2.

F. orizabensis populations declined at site one as their major food source became scarce (Fig. 1B). Pest and predator populations failed to recover to high densities during the spring and early summer of 2002 despite plentiful flush growth on trees for feeding and reproduction. No significant differences in thrips-days were observed at site one between release and control plots for densities of *S. perseae* ($t = 0.44$, $df = 10$, $p = 0.67$) (Fig. 2A) or *F. orizabensis* ($t = 1.69$, $df = 10$, $p = 0.12$) (Fig. 2B).

At site two, *S. perseae* population densities were consistently lower on leaves in *F. orizabensis* release plots for the first 23 weeks of the trial (Fig. 1C) and *F. orizabensis* densities were similarly higher on trees in predator release plots for 70% of the sampling dates (Fig. 1D). No significant differences in thrips-days were observed between treatments for *S. perseae* densities ($t = 1.50$, $df = 8$, $p = 0.17$) (Fig. 2C). A significant difference in thrips-days for *F. orizabensis* was detected

between treatments ($t = 7.47$, $df = 8$, $p < 0.0005$). Predators were consistently recovered in higher numbers from trees in release plots (Fig. 2D).

3.2. Sticky card trends

At site one, *S. perseae* captures showed three distinct peaks, July–August, 2001, November–December, 2001, and January 2002 before declining to low levels in February 2002 (Fig. 3A). *F. orizabensis* capture incidence crashed in August 2001, and did not recover to any appreciable level in either the control or release plots (Fig. 3A). At site one, no significant effects by cardinal direction in thrips capture rates were detected, regardless of whether cards were deployed in release or control plots (data not shown). At site 2, *S. perseae* and *F. orizabensis* capture rates showed no discernible trends, and cardinal direction and proximity to either predator release or control plots exhibited no significant
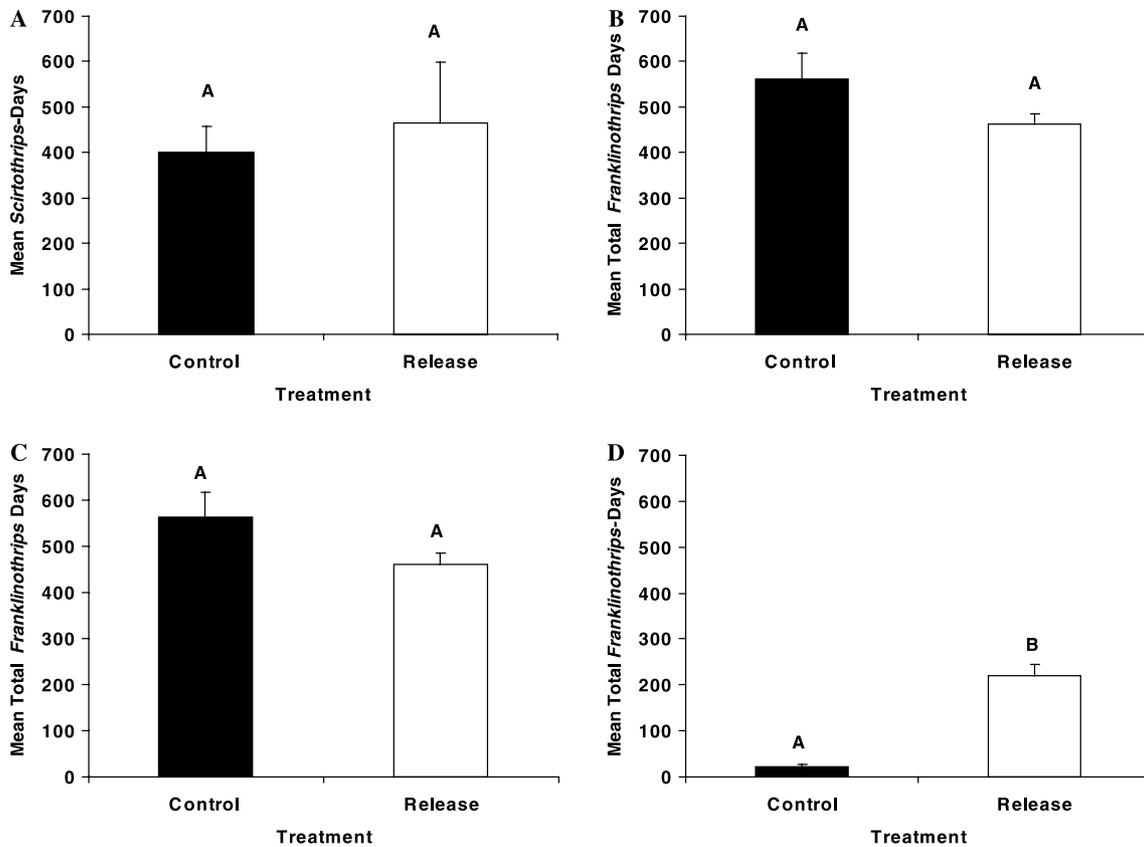
Fig. 2. Mean thrips-days (±SE) estimates for *S. perseae* in predator release and non-release (control) plots at sites one (A) and two (B). Mean thrips-days (±SE) estimates for *F. orizabensis* in predator release and non-release plots at sites one (C) and two (D). Means followed by the same letters are not significant at the 0.05 level.

effect on capture incidence (data not shown) (Fig. 3B). Cardinal direction has been previously shown to be unimportant in interpreting sticky card capture data for *S. perseae* and *F. orizabensis* suggesting these thrips fly under conditions enabling controlled flight rather than passive dispersal by prevailing winds (Hoddle et al., 2002c).

3.3. Quality control data

ANOVA results indicated significant interaction terms between study sites for adult emergence rates ($F = 57.17$, $df = 1$, $p < 0.005$) and source of predators ($F = 38.16$, $df = 2$, $p < 0.005$). There was no significant effect of month of release on emergence rates at study sites ($F = 0.03$, $df = 11$, $p = 0.23$). Similarly, interaction terms for sex ratio of emerged adults and study sites was significant ($F = 43.07$, $df = 1$, $p < 0.005$), as was study site and source of predators ($F = 27.07$, $df = 2$, $p < 0.005$). There was no significant effect of month of release on sex ratio at the two study sites ($F = 1.65$, $df = 11$, $p = 0.1$).

Mean proportion of emerged adults and female emergence (sex ratio) are presented below as (mean proportion ± SE) and means followed by the same let-ters within parentheses are not significantly different at the 0.05 level. Mean proportion of emerged adult *F. orizabensis* was highest for material from Insectary B that was released at site two and held in the laboratory for emergence ($0.88 \pm 0.01a$), intermediate for both laboratory emergence of Insectary A material used at site two ($0.84 \pm 0.03ab$) and combined field emergence of *F. orizabensis* from Insectary A and B at site two ($0.83 \pm 0.01ab$) (Fig. 4B). Mean emergence was lower for UCR reared *F. orizabensis* released at site one that was held in the laboratory ($0.75 \pm 0.03b$) and emergence was lowest for UCR-reared predators deployed in the field at site one ($0.66 \pm 0.02c$) (Fig. 4A).

Proportion of emerged females was highest for UCR-reared *F. orizabensis* released at site one ($0.47 \pm 0.02a$) (Fig. 4C), and lower but equivalent for predators reared by Insectary B and released at site one ($0.33 \pm 0.02b$), along with material from Insectary A material (0.32 ± 0.3) and Insectary B (0.29 ± 0.01) released at site two (Fig. 4D).

3.4. Field survivorship rates

The effect of food availability and sex of predator on mean longevity had a significant interaction term
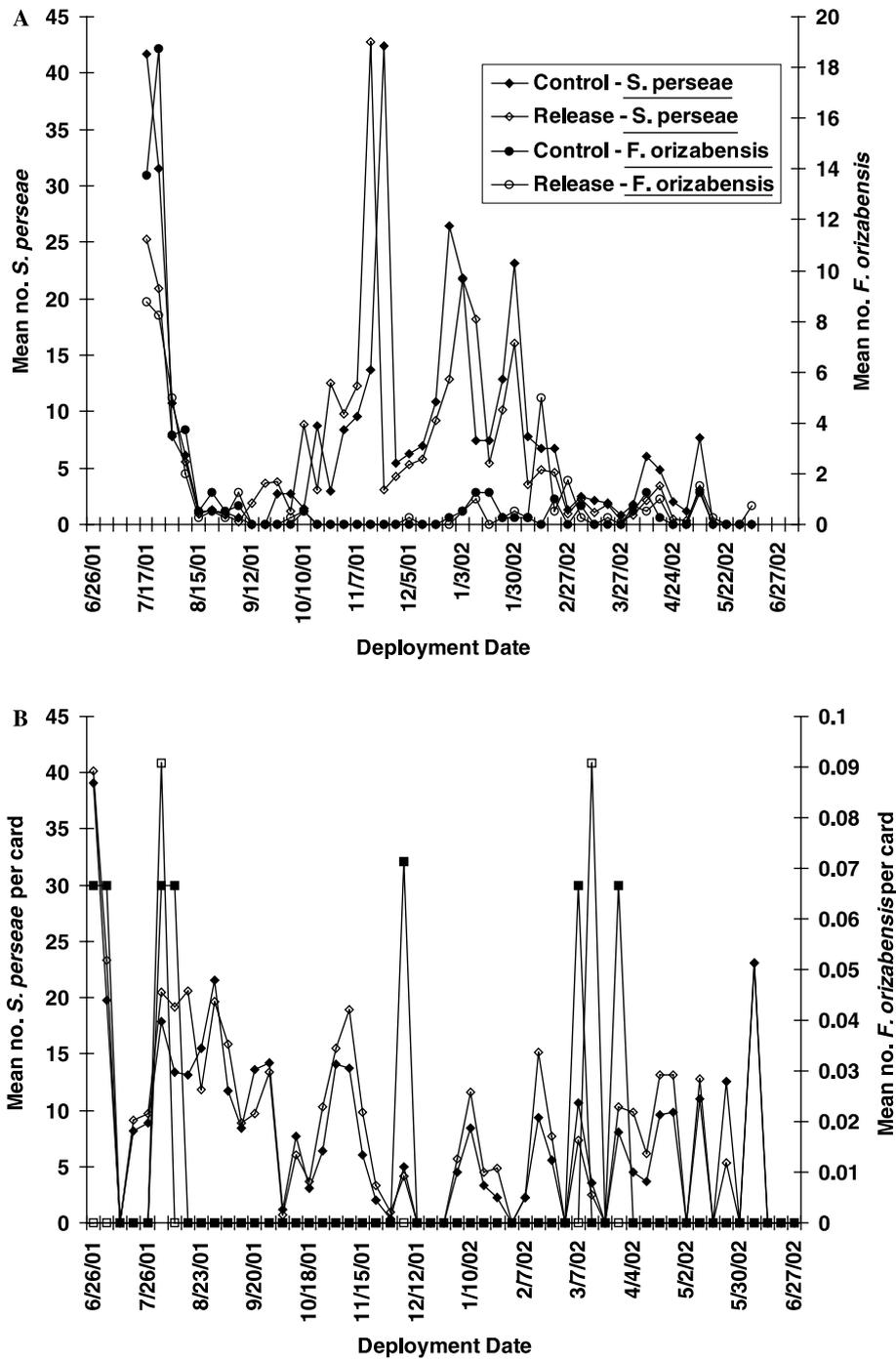
Fig. 3. Mean numbers of *S. perseae* and *F. orizabensis* caught on yellow sticky cards in predator release plots and non-release plots at sites one (A) and two (B).

($F = 13.66$, $df = 1, 5$, $p < 0.005$). When predators were not supplied food no significant differences in mean survivorship times were observed ($F = 0.01$, $df = 1, 33$, $p = 0.93$). When predators were provided with a leaf ($F = 45.94$, $df = 1, 36$, $p < 0.005$), 5% ($F = 25.63$, $df = 1, 33$, $p < 0.005$), 25% ($F = 79.07$, $df = 1, 32$, $p < 0.005$), 50% ($F = 34.37$, $df = 1, 38$, $p < 0.005$), or 100% food ($F = 55.03$, $df = 1, 36$, $p < 0.05$), females significantly outlived males (Fig. 5C). Within sex

comparisons across foods were highly significant for males ($F = 12.48$, $df = 5, 101$, $p < 0.05$) and females ($F = 41.87$, $df = 5, 107$, $p < 0.005$) (Fig. 5C). For males, mean daily longevity increased when the food allocation exceeded 25%. For females, availability of a leaf and 5% food were equivalent, and greatest increase in longevity was achieved when females were provided with 50 and 100% food (Fig. 5C). Weibull function fitting was significant for all diets across sex and significant differences
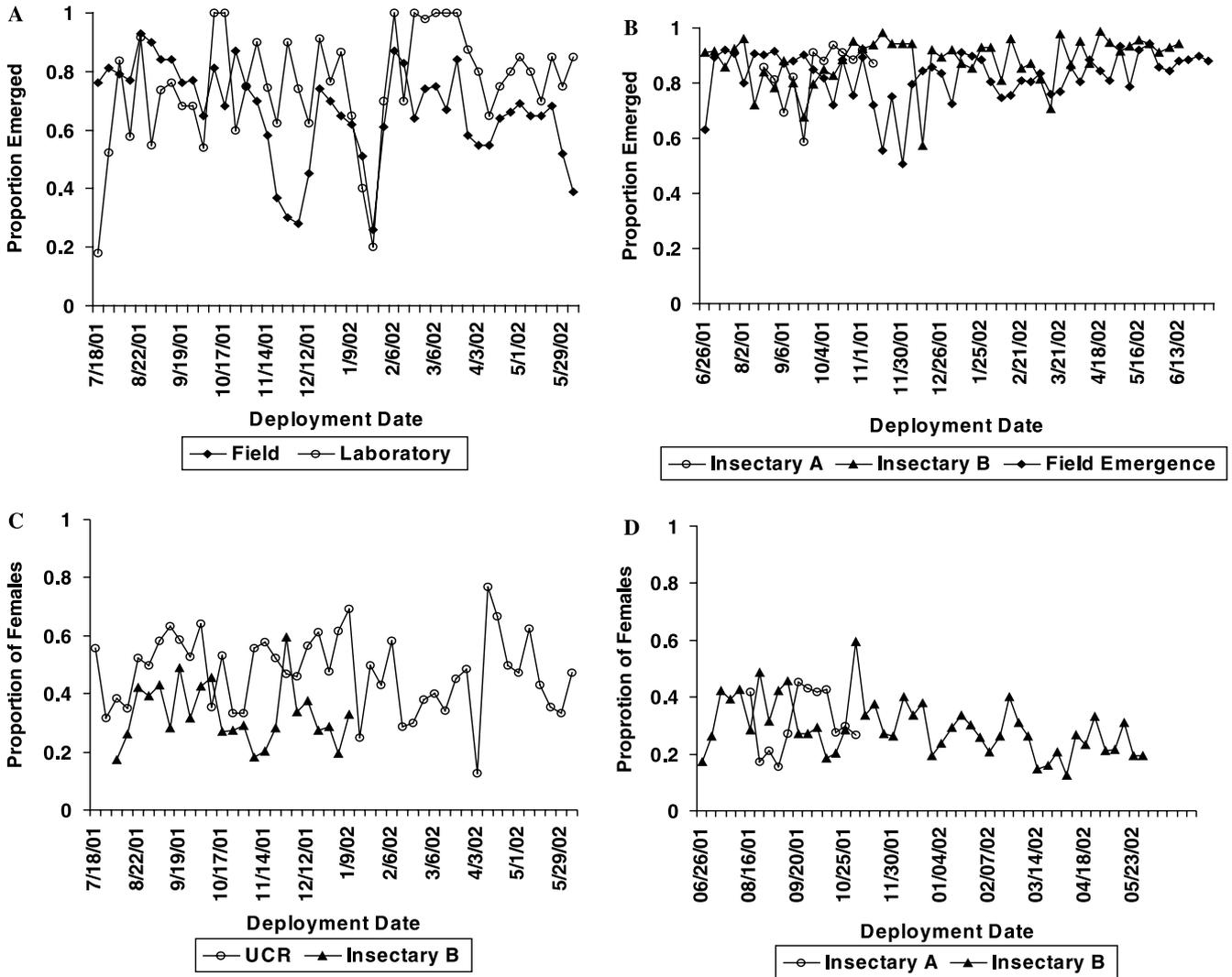
Fig. 4. Field and laboratory emergence of *F. orizabensis* released at site one (A) and two (B). Sex ratio of *F. orizabensis* reared at University of California, Riverside and Insectary B released at site one (C) and sex ratio of *F. orizabensis* mass reared by Insectaries A and B released at site 2 (D).

in median survivorship times (degree-days) as estimated by the Weibull model were detected for certain diets within and between sexes (Table 1).

4. Discussion

Weekly augmentative releases of *F. orizabensis* at 50 pupae per tree failed to suppress *S. perseae* populations on small (1.5–2 m in height, site two) and medium (4–5 m, site one) sized avocado trees. Although not statistically significant, the efficacy of *F. orizabensis* releases was most pronounced on small trees at site two (Ventura) where mean thrips-days calculations for *S. perseae* on release trees were 27% lower than non-release trees. Conversely, for larger trees at site one (San Marcos) thrips-days estimates for *S. perseae* were 16% greater on predator release trees in comparison to non-release trees. Significantly more predators were recovered from

the smaller trees at site two and thrips-days calculations for *F. orizabensis* were 10 times higher on release trees than control trees. This result suggests that predators were able to persist on small release trees in appreciable numbers, were not prone to abandoning trees onto which they were released, and may have reproduced on the low densities of *S. perseae* observed at site two.

At site one, thrips-days estimates for *F. orizabensis* were 18% higher on non-release trees when compared to release trees indicating that naturally occurring reproduction in this orchard was not being substantially augmented by releases, and that predator releases onto trees at this site were possibly detrimental to resident *F. orizabensis* populations. Silvers (2000) also demonstrated an inability of *F. orizabensis* to suppress *S. perseae* following augmentative releases onto avocado trees. In Silvers's (2000) study, poor predator quality and high levels of mortality resulting from transit stress were considered major factors influencing the negative
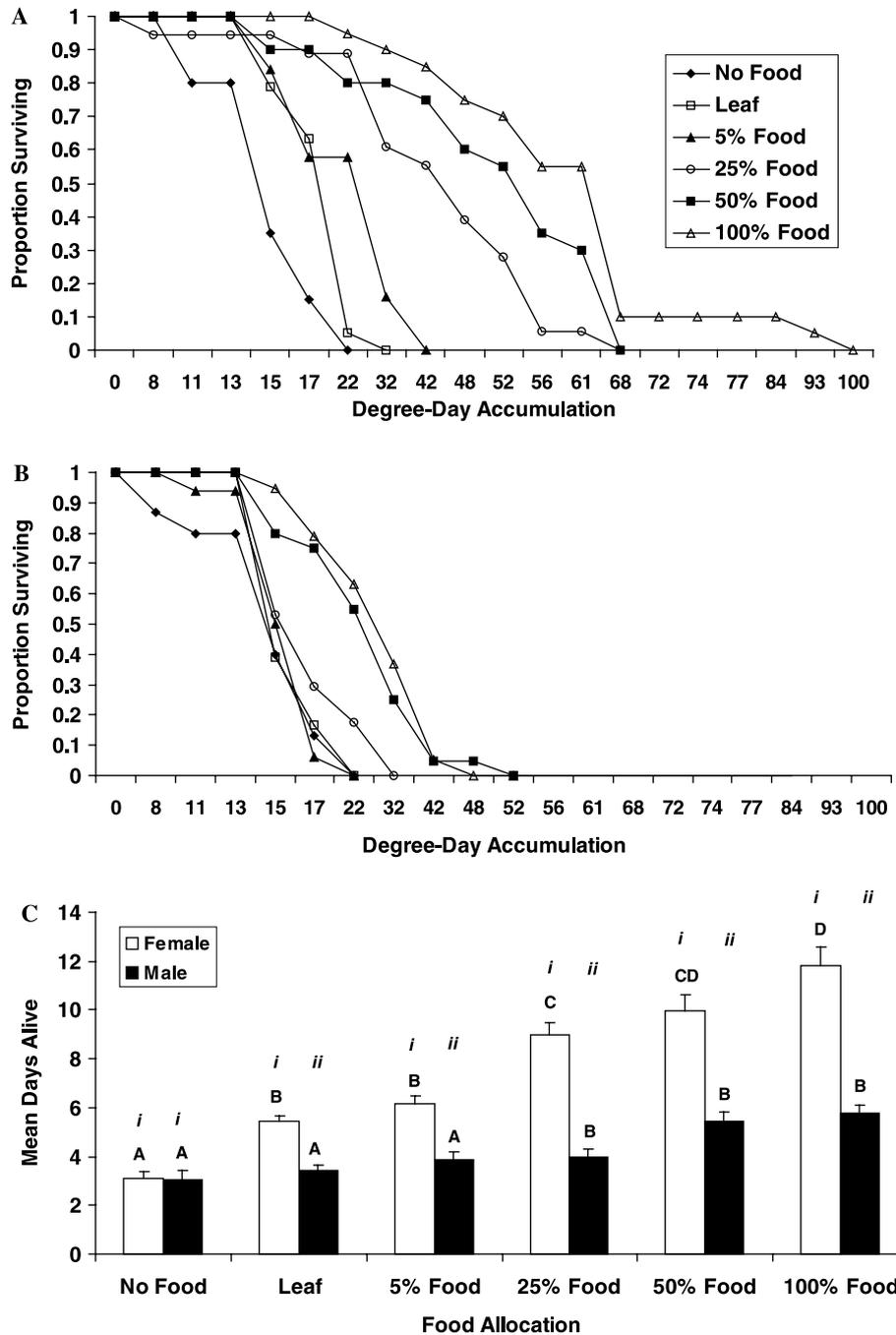
Fig. 5. The effect of different foods or amounts of food on survivorship rates for female (A) and male (B) *F. orizabensis*. Mean number of days (±SE) that male and female *F. orizabensis* survived for at an average temperature of 14.92 °C (minimum temperature = 2.89 °C; maximum = 30.71 °C) (C). Means with the same capital letters across treatments are not significantly different between sexes at the 0.05 level. Means with the same italicized Roman numerals comparing sexes within food treatments are not significantly different at the 0.05 level.

outcome of this trial rather than the inherent ineffectiveness of augmentative release of this predator.

Average emergence rates for *F. orizabensis* in the laboratory were high, ranging 75–88% across all three suppliers. Average field emergence rates were lower than those observed in the laboratory ranging 67–83% across sites one and two. The sex ratio of mass-reared *F. orizabensis* across all three suppliers was strongly male

biased, with 53–71% of predators that emerged across all release dates, both experimental sites, and three insectary operations being male. Temperature (Hoddle et al., 2000) and food quality (Hoddle et al., 2001a) affect sex ratio of *F. orizabensis* offspring. Neither of these factors would appear to be significant in mass-rearing *F. orizabensis* as predators were kept at 24–27 °C, an optimal temperature range, and fed irradiated

Table 1
Weibull function parameter estimates and median survivorship (50%) times in day-degrees for adult male and female *F. orizabensis* provisioned with different foods and allocations

Sex and diet	a (±SE)	b (±SE)	ANOVA	Degree-day accumulation to median survivorship
Males				
0% food	15.01 ± 0.37	6.31 ± 1.31	$F = 177, df = 2, 5, p < 0.005$	14.16a,i
Leaf	15.09 ± 0.30	9.37 ± 2.07	$F = 248, df = 2, 4, p < 0.005$	14.51a,i
5% food	15.10 ± 0.15	12.84 ± 1.99	$F = 968, df = 2, 4, p < 0.005$	14.67a,i
25% food	16.03 ± 0.47	8.84 ± 2.88	$F = 131, df = 2, 5, p < 0.005$	15.37a,i
50% food	27.61 ± 1.03	2.87 ± 0.31	$F = 775, df = 2, 8, p < 0.005$	24.29b,i
100% food	30.36 ± 0.99	3.11 ± 0.32	$F = 1000, df = 2, 7, p < 0.005$	26.98b,i
Females				
0% food	14.89 ± 0.34	6.59 ± 1.31	$F = 206, df = 2, 4, p < 0.005$	14.09a,i
Leaf	18.67 ± 0.42	6.90 ± 0.89	$F = 1309, df = 2, 5, p < 0.005$	17.71b,ii
5% food	25.66 ± 1.71	3.05 ± 0.61	$F = 232, df = 2, 6, p < 0.005$	22.75c,ii
25% food	45.57 ± 1.39	2.78 ± 0.34	$F = 680, df = 2, 11, p < 0.005$	39.94d,ii
50% Food	56.31 ± 1.75	3.57 ± 0.66	$F = 501, df = 2, 11, p < 0.005$	50.82e,ii
100% food	62.89 ± 0.88	4.96 ± 0.46	$F = 1497, df = 2, 17, p < 0.005$	58.41f,ii

Means with the same letters across treatments are not significantly different between sexes (95% CI). Means with the same italicized Roman numerals comparing sexes within food treatments are not significantly different (95% CI).

E. kuehniella eggs, a favored food type. Since *F. orizabensis* is haplodiploid (Hoddle et al., 2000), we speculate that a rearing stress such as over-crowding, in particular, high encounter rates amongst females, may result in male biased sex ratios. Such a phenomenon is integral to Local Mate Competition (LMC) theory and sex ratio allocation in haplodiploid parasitic Hymenoptera. LMC theory predicts that when foundress numbers, or female–female encounter rates are high, females tend to produce more male offspring (Godfray, 1994). Increased male production occurs because with increasing numbers of females contributing offspring to the group, each female has a decreasing influence on the sex ratio of the mating group, and females subsequently reduce investment in daughters (Luck et al., 1999). Factors influencing sex ratio allocation in haplodiploid Thysanoptera are not well studied and this area deserves more research attention, particularly if efficient mass rearing of Thysanoptera as biological control agents is to occur.

Field longevity of *F. orizabensis* was significantly influenced by predator sex and resource availability. Releases of predators into orchards with little or no prey availability will result in 50% death after accumulation of 14–23 degree-days. Males tended to die earlier than females and this may be attributable to competition for food in vials. However, in the laboratory where food is not a limiting factor, male *F. orizabensis* exhibit reduced longevity (Hoddle et al., 2000). Promotion of early season pre-emptive releases of predators in orchards in advance of an anticipated *S. perseae* outbreak does not appear warranted as predators will most likely be unable to establish in substantial numbers when high quality prey is not plentiful. Commonly encountered tetranychid avocado pests such as persea mite, *Oligonychus perseae* Tuttle, Baker, and Abbatiello and avocado

brown mite, *Oligonychus punicae* (Hirst) are unsuitable prey for larval development and adult reproduction when comprising the bulk of the diet for *F. orizabensis* (Hoddle et al., 2001a). This may explain why *F. orizabensis* was uncommon in southern California avocado orchards until *S. perseae* successfully established after these two mite pests.

Given the state of the current mass-rearing technology and associated costs, variable emergence under field conditions, male biased sex ratios, and the apparent inability of augmentative releases of high numbers of *F. orizabensis* (on average, under field conditions, approximately 34–42 predators were released per tree. The intended release rate was 50 *F. orizabensis* per tree) to control *S. perseae* on small trees, commercial implementation of this predator for control of thrips pests in perennial orchards is unwarranted. A more promising avenue of investigation could be assessment of the efficacy of *F. orizabensis* releases for control of thrips pests, such as western flower thrips, *Frankliniella occidentalis* (Pergande), in high value crops grown in protected environments (e.g., greenhouse grown ornamentals and vegetables).

There are no successful augmentative release programs for controlling thrips in outdoor crops. Often, naturally occurring biological control agents in outdoor crops are not present in sufficient numbers as their populations build too slowly to control rapid outbreaks of pest thrips (Parrella and Lewis, 1997). Consequently, insecticides are applied for pest thrips control and these may be detrimental to natural enemy persistence in orchards.

Applications of the insecticides spinosad and abamectin are regularly used for *S. perseae* control. Both insecticides exhibit translaminar activity when mixed with refined narrow range petroleum oils and have short

leaf surface residual times that minimize direct contact with non-target organisms. Behavioral studies have revealed that *F. orizabensis* will spend around 2–5% of its time budget probing leaves with mouthparts and feeding on leaf juice, and 85–90% of adults engage in this activity on average for 7–13 s (Hoddle, 2003a). In field situations where translaminar insecticides have been applied, this may result in predators ingesting toxins which cause their death. *F. orizabensis* populations have been observed to decline for up to 17 days following applications of spinosad and abamectin (Silvers, 2000; Yee et al., 1999).

Therefore, a sustainable and cost effective management program for *S. perseae* in California avocado orchards will require maximal exploitation of naturally occurring populations of antagonists as augmentative predator releases appear ineffective; reduced reliance on insecticides will be needed to minimize upset to natural enemy populations and slow resistance development by *S. perseae*; and development and greater utilization of novel cultural control strategies that disadvantage pest developmental and reproductive success are needed to compliment biological and chemical control. Long-term efficient management of *S. perseae* will only be attainable within an integrated pest management framework (Hoddle et al., 2002a).

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