Biological Control of Avocado Thrips: Revisiting the Efficacy of Green Lacewing Releases

New Project: Year 1 of 1

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Benefit to the Industry

Avocado thrips, *Scirtothrips perseae* Nakahara (Thysanoptera: Thripidae), was discovered in California in July of 1996, and spread rapidly from two initial sites of discovery near Port Hueneme in Ventura County and at the Irvine Ranch in Orange County. Economic losses attributable to avocado thrips have been calculated using 1998 pack-out records indicated an annual short-run loss to avocado growers of between $7.6 and $13.4 million in 1998 from the combined effects of losses in quality and increased production costs associated with avocado thrips management. Economic losses to avocado thrips continue to accrue annually, but the magnitude of decreased revenue will vary yearly depending on the severity of thrips infestations, costs of control (biological or chemical), percentage of crop damaged, severity of damage, and market value for harvested fruit.

Several natural enemies attack various *Scirtothrips* spp. but overall, the level of biological control achieved against pestiferous species is disappointing. For example, predators associated with avocado thrips in California include predaceous mites (e.g., Phytoseiidae), various spider species, lacewings (Chrysopidae), and predaceous thrips (Aeolothripidae [*Aeolothrips kuwanii* and *Franklinothrips orizabensis*]). In many situations, natural biological control is inadequate to reduce severe fruit damage.

Some research has been done with augmentative release of natural enemies against various *Scirtothrips* spp. Grafton-Cardwell & Ouyang (1995) released up to 2,000 *E. tularensis* per tree against citrus thrips but failed to achieve a reduction in citrus thrips fruit scarring. Khan & Morse (1999) released two species of lacewings, *Chrysoperla carnea* (Stephens) and *C. rufilabris* (Burmeister), against citrus thrips and observed significant reductions in thrips levels and fruit scarring with both species. Hoddle et al. (2003) have demonstrated that augmentative releases of the predatory thrips *F. orizabensis* are ineffective at controlling *S. perseae*. Silvers (2000) released *C. rufilabris* against *S. perseae* on top-worked trees and failed to observe any significant impact against *S. perseae*. Silver's work was subsequently criticized by Pest Control Advisors (PCA's) because predator release timings, release rates, and tree size were not representative of conditions or practices employed by commercial PCA's who have achieved control of *S. perseae* with augmentative releases of lacewings. The purpose of the work reported here was to revisit the issue of releases of *Chrysoperla carnea* for avocado thrips control and to work with cooperating PCA's and evaluate the efficacy of their release rates and strategies in commercial orchards treated with lacewings for *S. perseae* suppression.

Objectives

1. Field evaluation of commercially available green lacewing larvae for avocado thrips control when applied by PCA's.
2. Determine longevity of lacewing larvae when supplied with varying amounts of food.
3. Laboratory investigation of lacewing larvae predation of avocado thrips larvae and *Franklinothrips orizabensis* larvae and adults.

Materials and Methods

Field Sites: Two commercial orchards were selected for evaluation studies. At each site 12 blocks of 15 trees were set up. Eight blocks were subjected to commercial releases of lacewings applied by a PCA. In these eight blocks two release techniques were evaluated in each of four blocks. Lacewings were deployed at both sites as eggs. Release strategy one was deployment of lacewing eggs glued to paper. Approximately 5000 lacewing eggs were glued to 30 perforated paper squares measuring 29 mm x 25 mm to give approximately 166 eggs per square. Paper squares were stapled at a rate of one per tree to the undersides of mature interior leaves (lacewing eggs facing away from the leaf) adjacent flush leaves that could support avocado thrips. Release strategy two used a motorized back-pack sprayer to spray lacewing eggs mixed with two liters of corn grits onto release trees. Lacewing eggs were applied by the PCA when it was estimated that 75% of eggs had hatched effectively resulting in a mixture of eggs and larvae being applied to trees. Each release strategy applied 208,333 lacewing eggs per acre (125,000 eggs were released in 0.6 acres the total size of each of the 4 release blocks used for each treatment). At each site, avocado thrips densities in the lacewing release blocks were compared to four non-release control blocks.

Site one was at San Marcos (San Diego County) and consisted of heavily flushing trees that had been top-worked 2 years previously. This site had been repeatedly treated with lacewings for avocado thrips control the previous season. Trees were approximately 5 meters in height when the trial commenced in March 18, 2003 and ceased July 9, 2003. Site two was in Irvine (Orange County) and consisted of mature avocado trees 15-20 meters in height with a thick interlocking canopy. Lacewings had been released previously at this site for *S. perseae* control. Lacewing releases at site 2 commenced July 25, 2003 and ended July 17, 2003. Lacewing release start and end dates and frequency of releases were determined by the PCA's monitoring their respective orchards.

Population Density Data & Analysis: Every two weeks ten trees were randomly selected in each experimental block of 15 trees and ten ¾ expanded leaves were examined and numbers of avocado thrips larvae and adults per leaf were recorded. In the center of each experimental block a yellow sticky card was deployed on a stake 1.5 m above the ground. Every two weeks the card was replaced and the exposed card was examined for *S. perseae*, *F. orizabensis*, and *C. carnea* adults. Thrips-days for *S. perseae* in release and non-release plots on leaves or sticky cards were calculated using geometric summation for each experimental block to estimate the area under population curves, by calculating the sum of products of the number of individuals at each sampling date and the time interval between sampling dates (Carey, 1993). Total thrips-days per experimental block were calculated, averaged across blocks for each treatment, and compared

using ANOVA at the 0.05 level of significance (SAS, 1990) to determine if treatment effects existed for thrips counts on leaves. Two-way ANOVA with treatment and cardinal direction as major factors was used to determine if significant differences in densities of adult avocado thrips caught on sticky cards in experimental plots existed.

Quality Control Evaluation of Deployed Lacewing Eggs: Chrysoperla carnea eggs were obtained from a commercial insectary in southern California and used for both predator release methods. Hatching rates of eggs from the blower method were determined by taking a 20 ml aliquots of corn grits with lacewing eggs from the reservoir bottle attached to the blower on the day of application. The number of eggs, and larvae in aliquots were counted. Lacewing eggs glued to release cards were removed from orchards and returned to the lab where numbers of hatched and unhatched eggs were recorded.

Estimation of Numbers of Lacewing Eggs Applied with Blower to Individual Trees: The number of lacewing eggs and larvae that fell from trees being treated with the blower were determined by placing two wooden boxes (30 cm wide, 35 cm long, and 13 cm deep) under each of six randomly selected trees in plots being treated with the blower. Plastic panels attached to the tops of boxes were treated with tanglefoot which trapped corn grits, lacewing eggs and larvae. Plastic panels were removed after applications were completed, placed in clear plastic bags and returned to the lab where numbers of lacewing eggs and larvae were recorded. The area under each experimental tree in each blower plot was measured from the trunk to the edge of the radius; the height of each tree was estimated using a telescopic measuring pole. The volume of each tree was calculated as cylinder. The average volume of grits with lacewing eggs applied to each tree was calculated and the amount of material falling onto the ground as estimated from the sticky panels was subtracted from the volume applied per tree and the remainder was assumed to have stayed on the tree and was not blown through the canopy.

Survivorship Estimates for Lacewing Larvae Under Temperature and Food Regimens Approximating Field Conditions: To estimate field survivorship rates of lacewing when provided with varying amounts of food 15 first instar larvae (< 24 hrs of age) were randomly assigned to sealed plastic vial with one of six food treatments: (1) no food; (2) immature avocado leaf; (3) avocado pollen; (4) 15 irradiated *Ephestia kuehniella* eggs; (5) 150 *E. kuehniella* eggs; and (6) 300 *E. kuehniella* eggs. Because of inclement weather (i.e., rain caused *E. kuehniella* eggs to agglutinate), lacewing larvae in vials were kept in a temperature controlled cabinet under long days (L:D 16:8) instead of being deployed in the field. To approximate field conditions, average day and night temperatures in cabinets were calculated from Hobo data logger recordings made at 30 min. intervals at both field sites. Night time temperatures were set to $13^{o}C \pm 0.10$ and day time temperatures were $21.5^{o}C \pm 0.07$. Survival of larvae was recorded daily and cabinet temperatures were recorded every 30 min. with a Hobo data logger.

Survival times for lacewing larvae were analyzed using ANOVA at the 0.05 level of significance (SAS, 1990). Data for larval lacewing development times from Butler & Ritchie (1970) were used to determine the lower temperature threshold ($9.03^{o}C$) used in calculating degree-day accumulations from cabinet temperature data 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 $y = 100e - \left(\frac{x}{a}\right)^b$. This function was fitted using non-linear regression in SAS (1990) and used to estimate the degree-day accumulation for median survival times (50% survivorship) of lacewing larvae across treatments. Mean survivorship times in days across diets were compared using ANOVA and significant differences at the 0.05 level were determined using Duncan's Multiple Range Test (SAS, 1990).

Interactions Between Lacewing Larvae and Avocado Thrips Larvae: The prey preferences of first, second, & third instar lacewing larvae were determined by placing individual larvae on 5 cm x 5 cm avocado leaf arenas. Each leaf square was placed on a water-saturated foam pad and provisioned with five 1st and five 2nd instar avocado thrips larvae. Predation of avocado thrips larvae was determined visually at 1, 3, and 24 hr intervals post set up. Prey preferences and consumption rate comparisons were made within and across predator instars using Friedman's χ^2. Pairwise comparisons using methods detailed by Critchlow and Fligner (1991) were used to determine where significant differences existed in the change in the mean number of thrips larvae consumed between each observation interval.

Results

Population Density Trends and Sticky Card Monitoring: Releases of lacewings deployed either as eggs glued to release cards or deployed as a mixture of eggs and larvae applied with a mechanical blower to experimental trees failed to significantly reduce densities of avocado thrips at site one in Escondido (F = 0.11, df = 2,9, p = 0.90) or site two in Irvine (F = 0.41, df = 2,9, p = 0.67) when treatments were compared to each other and the non-release control plots (Fig. 1).

No significant differences in densities of adult avocado thrips caught on yellow sticky cards across treatments at site one in Escondido for treatment (F = 0.46, df = 2, p = 0.64), cardinal direction (F = 4.25, df = 1, p = 0.053), or the interaction between these two factors (F = 2.39, df = 2, p = 0.12) (Fig. 2A). Similar results were observed for site 2 at Irvine for treatment (F = 0.11, df = 2, p = 0.90), cardinal direction (F = 0.94, df = 1, p = 0.35) of the interactions between these two factors (F = 0.59, df = 2, p = 0.56) (Fig. 2B).

Quality Control of Deployed Lacewing Eggs: Egg hatch rates for both release methods were high, ranging from 70% - 76% when all samples across all sampling dates were combined (Table 1).

Table 1. Lacewing egg hatching rates for eggs glued to release cards or mixed with corn grits and blown onto release trees. Combined data was collected from two quality control samples made on March 20, 2003 and April 3, 2003 for site one in Escondido. Quality control data was collected at site two in Irvine on March 27, 2003 and April 10, 2003.

	Escondido (site one)			Irvine (site two)		
Treatment	*No. Hatched Eggs*	*No. Unhatched Eggs*	*% Egg hatch*	*No. Hatched Eggs*	*No. Unhatched Eggs*	*% Egg hatch*
Egg release cards	1221	497	71%	937	303	76%
Motorized blower r	695	302	70%	539	173	76%

Estimation of Numbers of Lacewing Eggs Applied with Blower to Individual Trees: On average the collection boxes covered 0.41% of the ground under a tree canopy and boxes on average trapped 6.03 eggs and larvae. Therefore approximately 35% of lacewing eggs and larvae sprayed onto trees fell to the ground and the remaining 65% of eggs and larvae either adhered to leaves or were blown through the canopy to land outside the study area.

Survivorship Estimates for Lacewing Larvae Under Varying Temperature and Food Regimens: Food availability had significant effects on average daily lacewing larvae longevity ($F = 19.98$, $df = 5,84$, $p < 0.005$) and degree-day accumulation to median survivorship (Table 1; Fig. 3). Larvae with access to irradiated *E. kuehniella* eggs lived longer than larvae provisioned with nothing, an avocado leaf, or avocado pollen (Table 1).

Table 1. Weibull function parameter estimates and median survivorship (50%) times in day-degrees for lacewing larvae provisioned with different foods and allocations. Means with the same letters across treatments for median degree-day survivorship (95% CI) and mean daily longevity are not significantly different (0.05 level of significance).

Diet	a (± SE)	b (± SE)	ANOVA	Degree-day accumulation to median survivorship	Mean (± SE) longevity in days
Nothing	26.69 ± 0.70	5.07 ± 1.33	F = 196, df = 2,4, p < 0.005	24.83a	1.47 ± 0.19a
Avocado leaf	26.16 ± 0.30	8.91 ± 2.79	F = 918, df = 2,4, p <0.005	25.11a	1.47 ± 0.17a
Avocado pollen	31.55 ± 1.23	7.78 ± 2.56	F = 119, df = 2,5, p < 0.005	30.09b	2.20 ± 0.31a
15 irradiated *E. kuehniella* eggs	74.66 ± 3.10	1.69 ± 0.19	F = 420, df = 2,13, p < 0.005	60.07c	6.20 ± 1.09b
150 eggs	156.50 ± 6.34	2.16 ± 0.28	F = 739, df = 2,20, p < 0.005	132.02d	13.80 ± 1.71c
300 eggs	205.40 ± 27.88	0.79 ± 0.15	F = 378, df = 2,23, p < 0.005	129.32e	14.53 ± 2.64c

Interactions Between Lacewing Larvae and Avocado Thrips Larvae: No significant differences in instar preference for avocado thrips larvae was demonstrated by first, second or third instar lacewing larvae at observation intervals 1, 3 and 24 hrs. Avocado thrips larvae were attacked by lacewing larvae as they were encountered. No significant differences in consumption rates of first instar avocado thrips larvae by first, second, and third instar lacewing larvae were observed for 1, 3 and 24 hr intervals (Fig. 4A). A significant difference in consumption rates of second instar avocado thrips larvae were observed at the 1 hr observation interval ($\chi^2 = 9.53$, $df = 2$, $p = 0.009$), but not at the 3 or 24 hr observation intervals (Fig. 4B). Significant differences in total

consumption rates of first and second instar avocado thrips larvae combined were observed across predator instars at the 1 hr (χ^2 = 6.95, df = 2, p = 0.03), and 24 hr (χ^2 = 8.97, df = 2, p = 0.01) observation intervals. No differences were observed at the 3 hr interval (χ^2 = 1.74, df = 2, p = 0.42) (Fig. 4C). Third instar lacewing larvae tended to consume the most first and second instar avocado thrips, with second instar predators exhibiting intermediate consumption rates and first instar lacewing larvae exhibiting the lowest overall consumption rates.

Discussion

Augmentative releases of *C. carnea* applied to avocado trees either as eggs glued to paper squares or sprayed onto trees at 75% egg hatch with a motorized blower failed to reduce densities of avocado thrips larvae and adults when compared to control blocks that received no lacewing treatments. Sticky card captures of adult avocado thrips failed to show any reduction in adult flight activity or densities. No significant differences in capture rates across cardinal directions were observed. This supports earlier observations and suggests that avocado thrips adults fly only when flight can be controlled and not subject to the vagaries of breezes.

Application of lacewing eggs and larvae with a motorized blower results in at least 35% of applied product falling to the ground. The amount of material blown through the canopy was not measured. When taken together these data suggest that releases of lacewing eggs glued to paper squares or mixtures of lacewing eggs and larvae applied mechanically are ineffective at controlling avocado thrips in commercial orchards at rates recommended by Pest Control Advisors. Lacewing larvae die within 1-2 days if prey is not procured. Consequently pre-emptive releases of lacewing larvae in anticipation of an avocado thrips outbreak may be unwarranted as predators will die of starvation. Additionally, if predators are not released in close proximity to prey that is easily located the majority can be expected to die of starvation.

Lacewing larvae feed voraciously on avocado thrips larvae and do not show preferences for particular instars. Third instar predators tend to consume more prey than smaller predators. All three instars of lacewing larvae first instar *Franklinothrips orizabensis* larvae, and second instar *F. orizabensis* were eaten by second and third instar lacewing larvae. Lacewing larvae were unable to consume adult female *F. orizabensis* and no predation by *F. orizabensis* larvae or adults on lacewing larvae was observed (data not shown in this report).

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Fig. 1. Population trends for avocado thrips at field site 1 in Escondido (A) and field site 2 in Irvine (B). Staple = lacewing eggs on paper squares were stapled to leaves; Blower = lacewing eggs and larvae applied mechanically with a motorized sprayer.
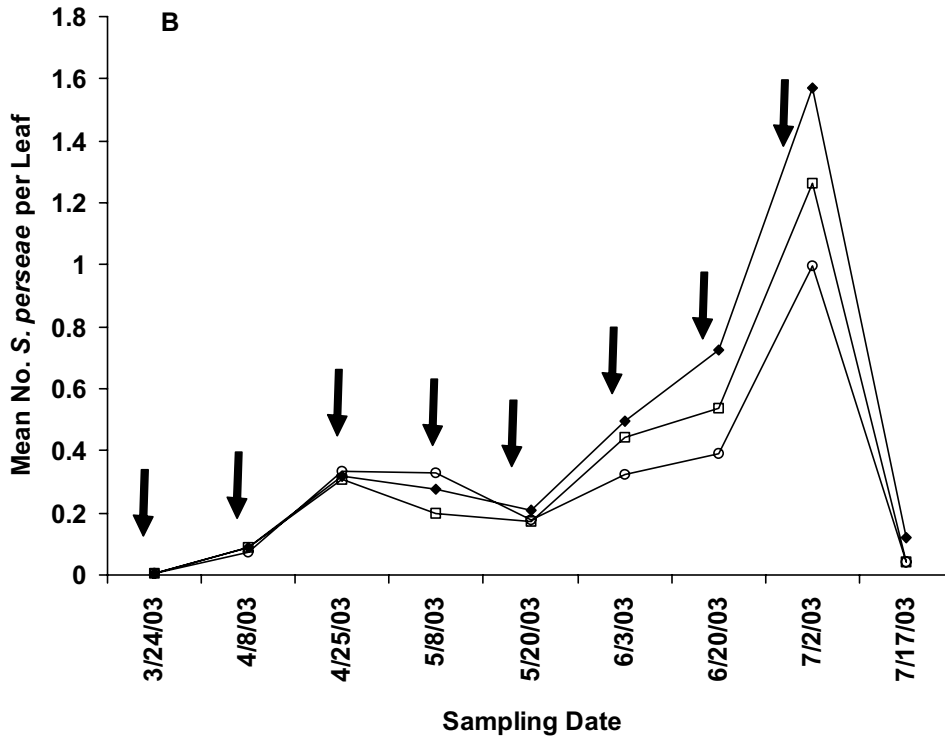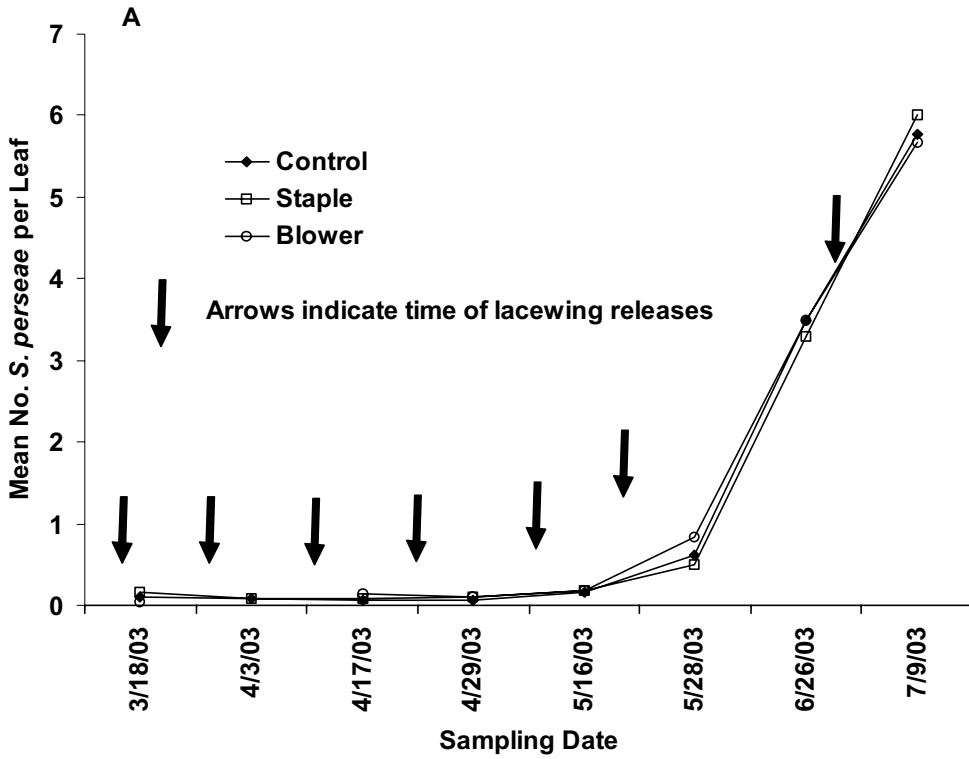
Fig. 2. Mean cumulative thrips days for site one (Escondido) (A) and site 2 (Irvine) (B). Means followed by the same letters are not significant at the 0.05 level (ANOVA).
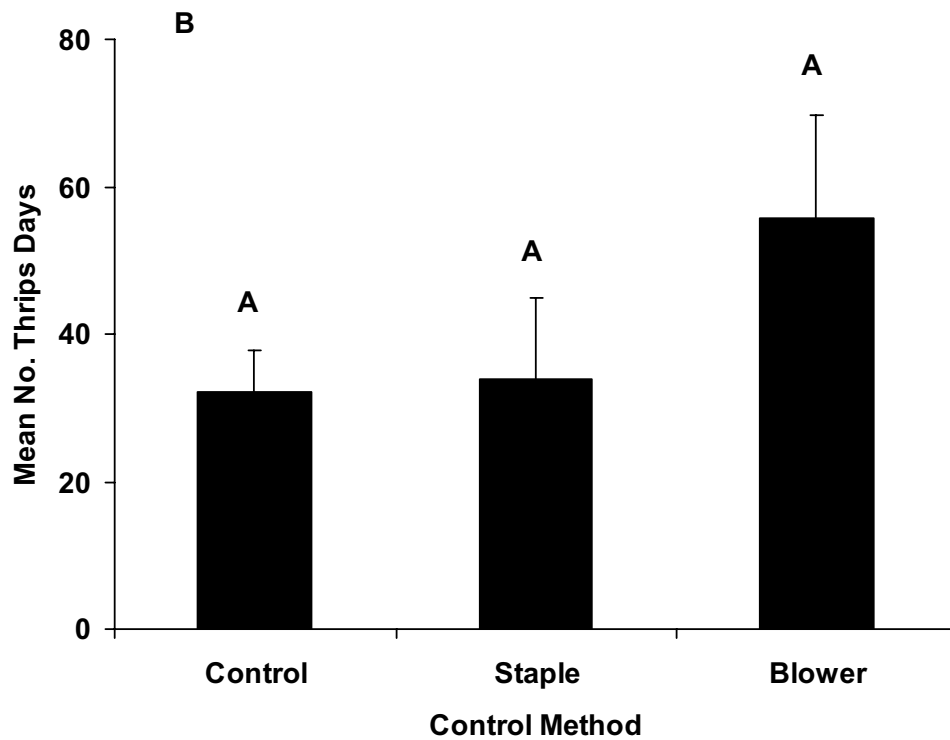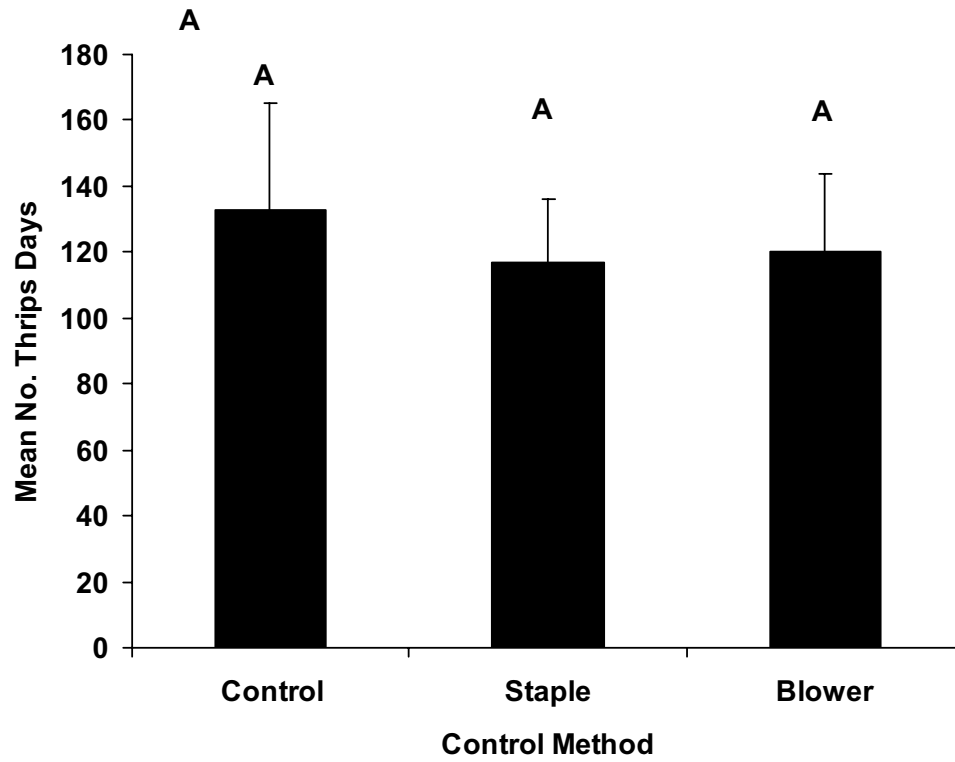
Fig. 3. Mean cumulative thrips days on yellow sticky cards at site one (Escondido) (A) and site two (Irvine) (B). Staple = lacewing eggs on paper squares were stapled to leaves; Blower = lacewing eggs and larvae applied mechanically with a motorized sprayer. Means followed by the same letters are not significant at the 0.05 level (ANOVA).
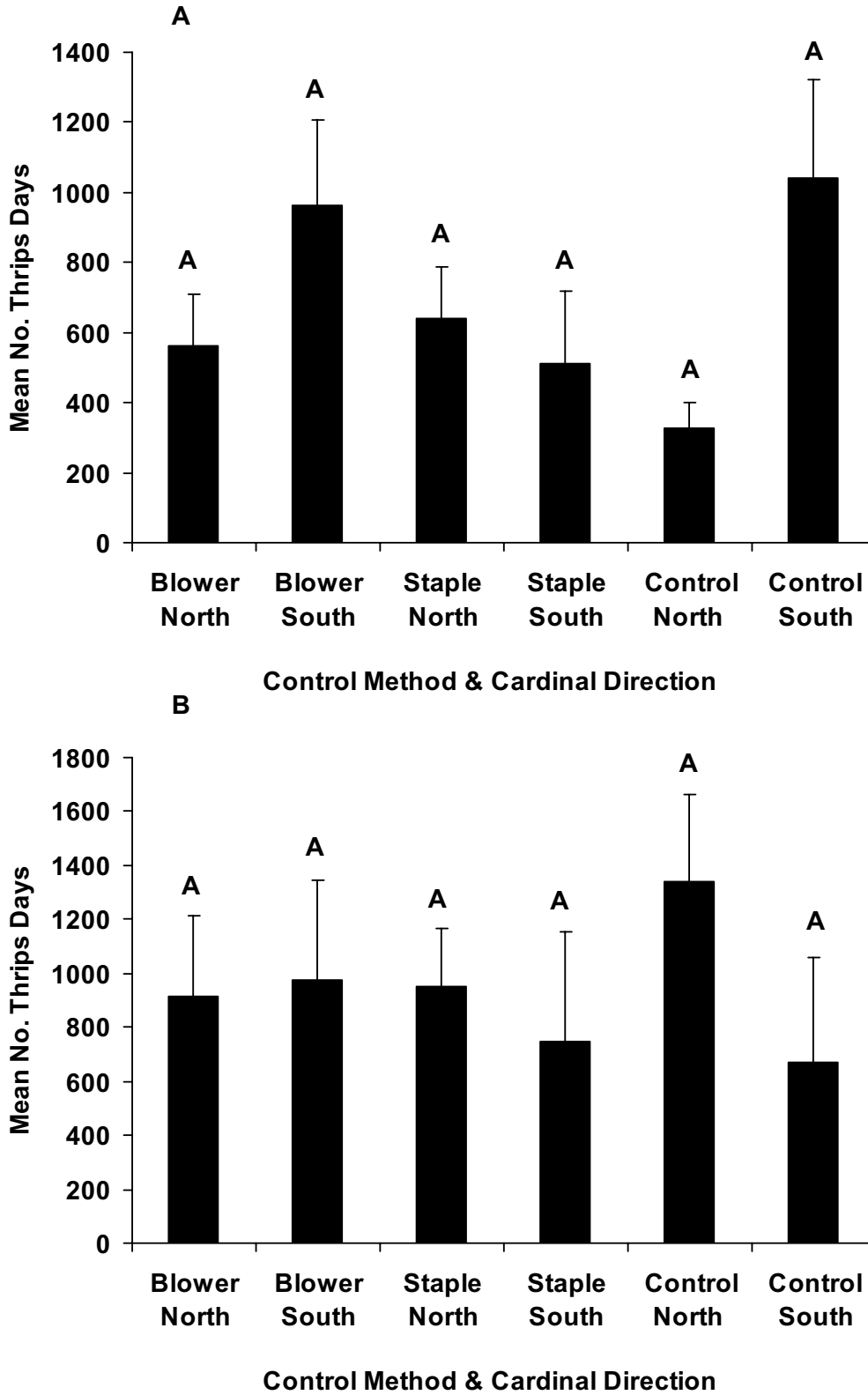
Fig. 4. The effect of different foods or amounts of food on survivorship rates for larval *Chrysoperla carnea*.
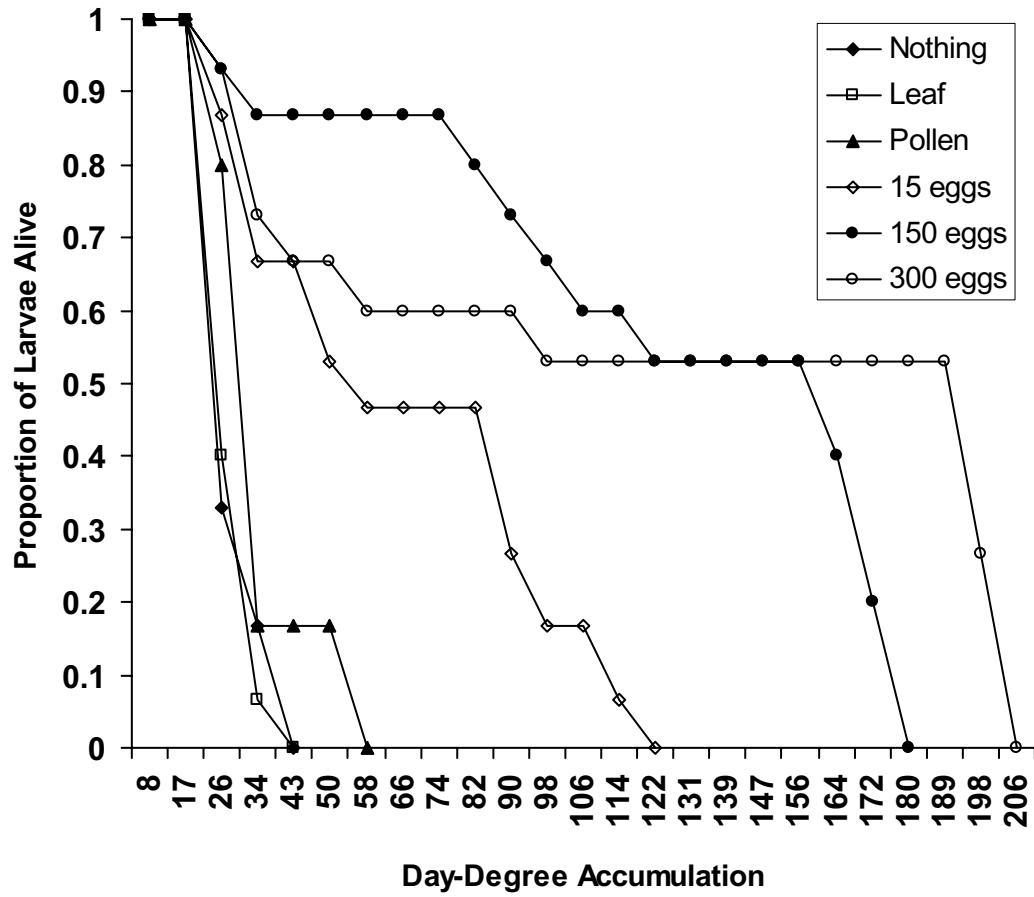
Fig. 5. Predation rates of first (A), and second (B) instar avocado thrips larvae and total larval consumption (C) by first, second, and third instar *Chrysoperla carnea* larvae at three different observation intervals.