Effects of Insecticide Use on Abundance and Diversity of Tomato Pests and Associated Natural Enemies in Hawai'i

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ABSTRACT. A survey of insects was conducted in Fall 1989 plantings of 7 commercial fresh market tomato farms in Maui, Moloka'i and Hawai'i islands. The primary pests which attacked the fruit were *Helicoverpa zea*, *Keiferia lycopersicella*, *Bactrocera cucurbitae* (Coquillett), and *Spodoptera exigua*. The key foliar pests were agromyzid leafminers and whiteflies. *Liriomyza sativae* and *L. trifolii* were the 2 leafminer species found attacking the foliage on all farms. *Liriomyza sativae* was the dominant species, and accounted for 68% of the leafminers reared from tomato leaflets. Nine species of leafminer parasitoids were observed in the 7 farms. Diversity of parasitoid species was 2 to 3 times lower in farms which used insecticides on a calendar basis than farms which applied insecticides only when pests reached nominal thresholds or used selective insecticides. *Diglyphus begini* was the dominant leafminer parasitoid, representing 85% of the parasites reared from tomato leaflets. The mean parasitism rates of leafminers over the planting period ranged 50–60% in farms using insecticides on a nominal or selective basis, and 8–17% in the calendar use farms. The predominant whitefly species was the greenhouse whitefly, *Trialeurodes vaporariorum*, which exceeded economic injury levels in 2 of the "calendar" farms for up to 33% of the sampling periods. Irregular ripening disorder of tomatoes, induced by *Bemisia tabaci* Biotype B was observed for the first time in the state of Hawai'i in 1 site on Hawai'i island. Potential management alternatives for key pests of tomatoes in Hawai'i are discussed.

INTRODUCTION

Fresh market tomatoes are a principal vegetable crop in the state of Hawai'i. In 1989, they were valued at 3 million dollars, acreage was 101 ha, and the total production was about 130 metric tons (Anonymous 1990). Several pests inflict yield reductions indirectly by foliar feeding. These include the agromyzid leafminers, *Liriomyza sativae* Blanchard and *L. trifolii* Burgess, greenhouse whitefly, *Trialeurodes vaporariorum* (Westwood), and the sweetpotato whitefly, *Bemisia tabaci* (Gennadius). *Bemisia tabaci* Biotype B is an important vector of several plant viruses and has been associated with other plant disorders of unknown etiology (Brown & Costa, 1992, Costa & Brown 1991, Hoelmer et. al. 1991, Bharathan et al. 1990, Schuster et al. 1990). Irregular ripening is a relatively new disorder of tomato, and was first recorded in Florida in 1987 (Maynard & Cantliffe 1989). The disorder is characterized by incomplete ripening of longitudinal sections of fruit. Symptoms are associated with feeding of *B. tabaci* and symptoms are more severe with increasing density of whitefly feeding (Schuster et al. 1990).

About 17 parasitoid species were introduced by the Hawai'i Department of Agriculture in the 1970s to control *Liriomyza* leafminers and whiteflies (Funasaki et al. 1988). As a complex, several parasitoid species appear to provide effective control in watermelon (Johnson 1987). Of these, *Chrysonotomyia punctiventris* (Crawford), *Halticoptera circulus* (Walker) were the predominant parasitoids in watermelon. However, extensive use of insecticides has been reported to adversely affect them (Johnson et al. 1980). In tomato, the eulophids, *Diglyphus begini* (Ashmead) and *D. intermedius* (Girault) were commonly observed in tomato fields in O'ahu (M.W. Johnson, unpubl. data).

Parasites such as *Encarsia formosa* Gahan and *E. transvena* Timberlake have been introduced for the control of greenhouse whitefly, but appear to be rare in tomatoes and

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other vegetable crops (Gerling 1983). Preliminary observations in the greenhouse indicate that the hemipteran omnivore, *Cyrtopeltis modestus* Distant, may be an important predator of the greenhouse whitefly. It is predaceous on a variety of other insects including *Helicoverpa* (= *Heliothis*) *zea* (Boddie) eggs and larvae, and *Liriomyza* larvae (Illingworth 1937, Parella & Bethke 1982). However, *C. modestus* feeds both on the stems and blossoms of tomato plants and decreases fruit set (Illingworth 1937).

The primary direct pests of tomato fruit include the tomato fruitworm, *H. zea* , tomato pinworm, *Keiferia lycopersicella* (Walsingham), beet army worm, *Spodoptera exigua* Hübner, the southern green stink bug, *Nezara viridula* (Linnaeus), and the melon fly *Bactrocera cucurbitae* (Coquillett). In general, natural enemies do not reduce levels of fruit infestation below 5%, and insecticides are used to control these pests. Application of pesticides often result in significant outbreaks of pests such as the whiteflies and leafminers via development of pesticide resistance and/or suppression of natural enemies.

The objectives of our study were to: 1) classify the relative importance of the major pests of commercial tomatoes in Hawai'i; 2) determine the species diversity of important natural enemy species; and 3) evaluate the impact of grower management practices on pest and natural enemy populations.

MATERIALS AND METHODS

Studies were conducted in 7 commercial tomato plantings: Kula, Maui (450 m and 900 m elev.); Ho'olehua, Moloka'i; Glenwood, Volcano, Captain Cook, and Kealakekua, on Hawai'i Island, beginning 22 September 1989 and ending 23 January 1990. Surveys were initiated from the second to fourth week after tomatoes were transplanted in the field and continued until the fourth–sixth tomato harvest. The size of tomato plantings surveyed ranged from ca. 0.4–4 ha. Black plastic mulch and drip irrigation lines were laid along the rows and tomato transplants were planted in holes made in the plastic. All tomatoes except plantings from the 2 farms in Maui were staked and trellised. Tomatoes were pruned to 2 main branches at least once during the planting cycle. Tomatoes in Glenwood and Volcano were grown in commercial shade houses.

In September 1989, growers from each of 7 farms were interviewed to determine the type and frequency of chemical and biological control used. The farms were classified by 3 main types of management tactics, and included: 1) *Calendar*: insecticides toxic to a wide range of insects (e.g., methomyl, oxamyl, dimethoate, endosulfan, fenvalerate and esfenvalerate) were applied on a regular basis. Decisions to apply insecticides were made without regard to insect pest infestation levels; 2) *Nominal thresholds*: broad-spectrum insecticides were only applied when insect populations approached or surpassed damaging levels. Thresholds were based on growers' experience, not scientific determination. Timing of control tactics was based on periodic sampling and assessments of insect numbers by the grower; and 3) *Selective*: the microbial insecticide, *Bacillus thuringiensis kurstaki* (*Bt*) which is specific to a few lepidopteran pests (e.g., *H. zea*) was applied. Natural levels of parasites and predators were relied upon for leafminer and whitefly control.

Each farm was divided into 4 randomly selected sections, for weekly sampling for insects. Within each of the 4 sections, 15 tomato leaflets were collected at random and taken to the laboratory for counting and identification. Using a light microscope with back lighting, active leafminer larvae and parasitized larvae were counted. Immature whiteflies were also counted by placing a clear acetate grid with 1 cm^2 squares over the leaf undersurface (Johnson et al. 1991), and counting the number of whitefly nymphs and pupae at random on four 1 cm^2 sectors. Whitefly pupae were examined for the presence of parasitoids. After counting, leaves were held in paper cartons (Johnson et al. 1980) to allow for emergence of adult leafminers and parasitoids. After 5 weeks, adult leafminers and parasitoid species were identified.

Cyrtopeltis modestus, was sampled by shaking 5 flower bearing branches at random within each of the 4 sections of each farm, and counting the number of nymphs and adults falling onto a beating tray (35.5 cm. diam.).

Wing-style pheromone traps, each with a specific lure (Ecogen Inc., Goodyear, Arizona) were used to monitor the lepidopterans *K. lycopersicella*, *H. zea*, and *S. exigua*. A single trap was hung from a stake or trellis wire within the center of each farm. Traps were hung at the center of the tomato canopy and raised as the plants grew in height. Trap bottoms were replaced weekly, and moths were counted. Lures were replaced in each trap every 4 weeks. When tomatoes reached the mature green stage, 30 fruit from each of the 4 sectors of all farms except Kula 900 m were randomly selected and the fruit were examined for evidence of feeding damage caused by the lepidopterans and southern green stink bug. In addition, a number of fruit with oviposition scars ("stings") from melon fly were counted. Fruit samples were collected weekly for 4–8 weeks, depending on the duration of harvesting in each farm. Numbers of fruit damaged by each species was converted to percentages.

Statistics

The mean number of unparasitized and parasitized leafminer larvae per leaflet and whiteflies per cm^2 on each leaflet for each sample date were calculated, and also combined to calculate the mean number of insects recorded during the entire planting cycle. Species diversity of leafminer parasitoids in the different farms was calculated using the Shannon index of diversity (Magurran 1988):

$$H' = -\sum p_i \ln p_i \qquad (1)$$

where H′ = index of diversity, and p_i is the proportion of individuals found in the *i*th species. To calculate differences in diversity indices among the different farms, we calculated the variance of H′ and the *t* statistic ($P \leq 0.05$; Magurran 1988):

$$\text{Var } H' = \left\{ \left[\sum p_i (\ln p_i)^2 - (\sum p \ln p_i)^2\right] N^{-1} \right\} + \left[(S - 1)(2N^2)^{-1}\right] \qquad (2)$$

$$t = (H'_1 - H'_2)(\text{Var } H'_1 + \text{Var } H'_2)^{-1} \qquad (3)$$

Differences in percent parasitization of leafminers were analyzed using the General Linear Models Procedure and Sheffe's *F* test (SAS 1988) for pairwise comparisons between the 3 management categories.

RESULTS AND DISCUSSION

Insecticide Use

Of the 7 farms, insecticides were applied on a calendar basis in 3 farms: Glenwood, Volcano and Kula 900 m (Table 1). In these farms, primarily organophosphate and pyrethroid insecticides were used weekly or biweekly. More than 20 treatments were applied during the planting cycle in these farms. Three farms in Ho'olehua, Kealakekua, and Kula 450 m used "nominal thresholds." In 2 of the "nominal" farms, alternative treatments such as insecticidal soap, *Bt* and the mating disruptant, lycopersilure for tomato pinworm, were applied. The Kula (450 m) farmer's spray equipment did not adequately cover the foliage

Table 1. Insecticide use at seven tomato farms in Hawai'i.

Pesticide Use	Farm Site	Chemicals used	Targest pest(s)	No. of applications
Calendar	Glenwood	esfenvalerate	lepidoptera[1]	8
		methomyl	leafminer	5
		oxamyl	whiteflies, leafminer	7
		endosulfan	whitefly	2
				Total: 22
	Volcano	dimethoate	leafminer	6
		oxamyl	whitefly	5
		methomyl	lepidoptera, leafminer	1
		fenvalerate	leafminer, whitefly, lepidoptera	5
		insecticidal soap	whitefly	6
				Total: 23
	Kula 900m	mevinphos	lepidoptera	9
		methomyl	leafminer	9
		fenvalerate	lepidoptera	4
				Total: 22
Nominal	Kealakekua	esfenvalerate	lepidoptera	2
		endosulfan	whitefly	4
		methomyl	leafminer	2
		oxamyl	whitefly, leafminer	2
		B. t. k[2]	tomato fruitworm	6
		insecticidal soap	whitefly	5
				Total: 21
	Ho'olehua	lycopersilure[3]	tomato pinworm	2
		malathion + bait[4]	melon fly	2
		methomyl	leafminer, lepidoptera	2
		esfenvalerate	lepidoptera	1
		B. t. k.	tomato fruitworm	4
				Total: 11
	Kula 450m	disyston	leafminer	1
		azinphosmethyl	leafminer	1
		methomyl	whitefly, leafminer	2
		mevinphos	lepidoptera	2
		oxamyl	whitefly, leafminer	1
				Total: 7
Selective	Captain Cook	*B. t. k.*	tomato fruitworm	2

1. Lepidopteran pests: tomato pinworm, tomato fruit worm, and beet army worm.
2. *Bacillus thuringiensis* var. *kurstaki*
3. No Mate® (Ecogen, Goodyear, AZ)
4. Protein bait (Nulure®) added to insecticide and applied to wind break vegetation (Sudan grass)

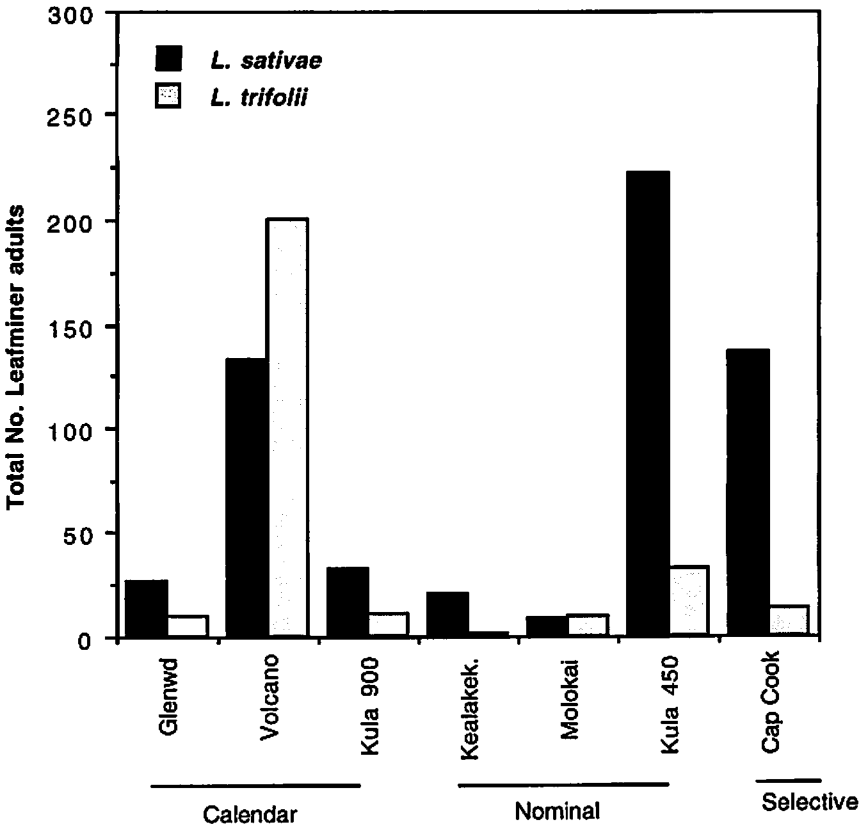

Fig. 1. Relative number of *Liriomyza sativae* and *L. trifolii* adults emerged from leaves throughout entire planting cycle in each of seven tomato farms in Hawai'i.

or fruit; and spray records were not available after the first month of planting (Table 1). In Ho'olehua, Sudan grass windbreaks were treated with malathion and protein bait to control melon flies, which commonly roost in weeds and other non-host plants (Nishida & Bess 1950). In the Captain Cook farm, *Bt* was applied early in the season for *H. zea* control and therefore classified in the "selective" management category.

Leafminers

Two agromyzids, *L. sativae* and *L. trifolii*, were observed in the 7 tomato farms (Fig. 1). *Liriomyza sativae* was the dominant species in 6 of the sites, accounting for 68% of the leafminer species collected. In contrast, *L. trifolii* populations were about 50% higher than *L. sativae* in the Volcano, which was a "calendar" farm. *L. trifolii* has developed resistance to insecticides more rapidly than *L. sativae* (Mason et al. 1987), and may have reached high levels because of a history of intensive insecticide use at this farm (Table 1).

Leafminer levels in Kula 900 m and Ho'olehua were below 0.2 per leaflet throughout the sampling period, and were not included in Fig. 2. In general, leafminer numbers were below 1 per leaflet in 2 of the 3 calendar farms, indicating susceptibility to insecticides. However, in the Volcano farm, levels exceeded 4 per leaflet for 3 weeks, despite more than 6 applications of insecticides for leafminers. This suggests that resistant popu-

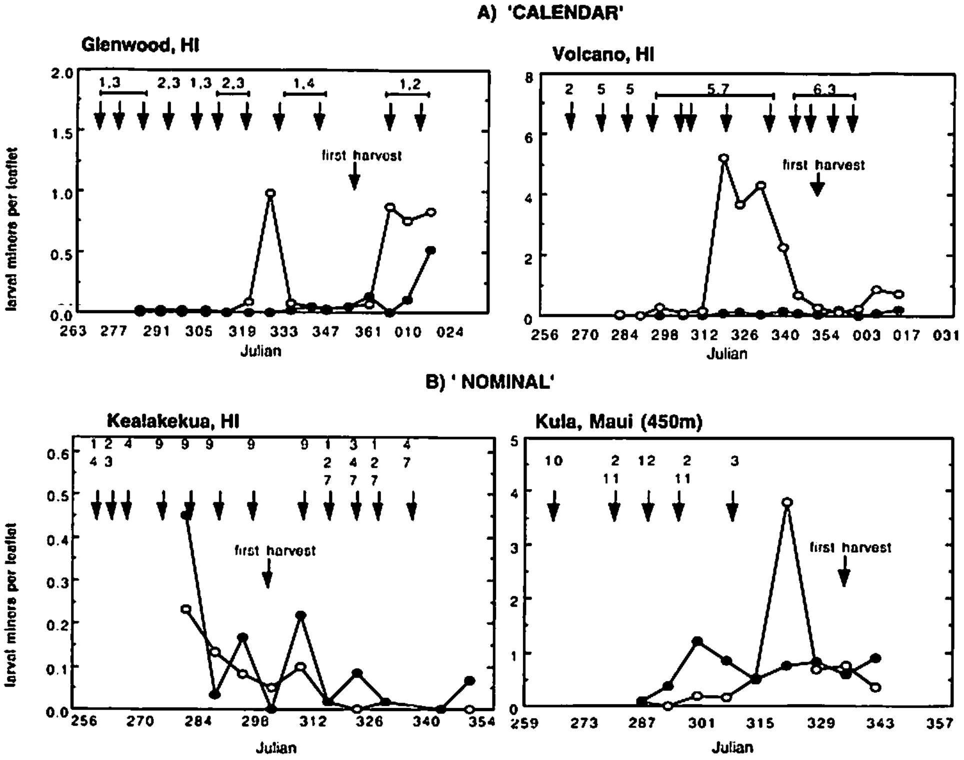

Fig. 2. Density of unparasitized (open circles) and parasitized (closed circles) larvae in Calendar and Nominal fields. Arrows indicate times of insecticide application. 1 = esfenvalerate, 2 = methomyl, 3 = oxamyl, 4 = endosulfan, 5 = dimethoate, 6 = fenvalerate, 7 = insecticidal soap, 8 = mevinphos, 9 = *B. thuringiensis kurstaki* (Btk), 10 = disyston, 11 = mevinphos, 12 = azinphosmethyl.

Table 2. Leafminer parasitoids collected in fresh market tomato farms in Maui, Moloka'i and Hawai'i.

	Calendar			**Nominal Threshold**			**Selective**
Parasitoid species:	**Glen-wood**	**Volcano**	**Kula 900m**	**Molokai**	**Kealakekua**	**Kula 450m**	**Capt. Cook**
Larval parasitoids:							
Chrysonotomyia punctiventris (Crawford)	0	0	0	0	0	46	1
C. formosa (Westwood)	0	0	0	0	1	0	0
Closterocerus utahensis Crawford	0	0	0	0	0	0	2
Diglyphus intermedius (Girault)	0	9	1	1	15	39	48
D. begini (Ashmead)	22	21	17	3	21	374	87
Hemiptarsenus semialbiclavus (Girault)	0	0	0	0	2	0	0
Larval - pupal parasitoids:							
Ganaspidium utilis (Beardsley)	0	0	0	3	0	16	2
Chrysocharis oscinidis (Crawford)	1	0	0	1	10	14	4
Halticoptera circulus Walker	0	0	0	0	3	1	4
Grand total	23	30	18	8	52	490	148
No. species	2	2	2	4	6	6	7
H' (diversity index) /[1]	0.18a	0.56b	0.43b	1.00c	1.41d	0.80c	0.87c

[1] Means within a row followed by different letters are significantly different ($P \le 0.05$, *t* test, Magurran 1988).

Table 3. Total parasitism rates of *Liriomyza* leafminers.

Pesticide Use/Farm	Mean % parasitism± SEM	Peak % parasitism
Calendar		
Glenwood	17.8 ± 6.1 b	66.7
Volcano	8.2 ± 4.1 b	61.1
Nominal threshold		
Kealakekua	52.0 ± 11.4 a	100.0
Kula 450	62.2 ± 8.4 a	100.0
Selective		
Captain Cook	57.8 ± 8.1 a	92.6

Means within a column followed by the same letter are not significantly different ($P < 0.05$; Scheffe's F test; SAS Institute 1988).

lations of *L. trifolii* were present. Populations were also below economically damaging levels in 2 of the nominal farms, which suggests that less frequent applications (i.e., Ho'olehua) were just as effective as calendar applications. Preliminary data indicates that tomato yields are reduced only when peak seasonal density exceeds 6 live larvae per leaflet, (M.W. Johnson, unpubl. data). Based on these levels, treatments for leafminer were probably unjustified in the calendar and nominal farms, and that leafminers may have been developing resistance to some of the materials used in Volcano and Kula 450 (i.e., methomyl, oxamyl; Fig. 2). Indeed, in the selective farm, which did not apply insecticides for leafminer, levels did not exceed 0.8 miners per leaflet (Fig. 2), which indicated that natural controls were effective.

Nine parasitic hymenopterous species associated with the leafminers were identified which included 6 larval and 3 larval-pupal parasitoids (Table 2). Larval parasitoids included *Diglyphus begini* (Ashmead), *D. intermedius* (Girault), *Chrysonotomyia formosa* (Westwood), *C. punctiventris* (Crawford), *Closterocerus utahensis* (Crawford), and *Hemiptarsenus semialbiclavus* (Girault). Larval-pupal parasitoids were *Ganaspidium utilis* Beardsley, *Chrysocharis oscinidis* (Crawford), and *Halticoptera circulus* (Walker). The 2 most common parasitoids were *D. begini* and *D. intermedius*, which accounted for 84.8% and 14.6% respectively of the parasitoids collected from tomato leaflets over the entire planting cycle (Table 2). *Diglyphus begini* is also reportedly the most common parasitoid associated with tomatoes in California, while *C. formosa* and *D. intermedius* are the dominant species in Florida tomatoes (Johnson & Hara 1987). High levels of resistance in *D. begini* to pyrethroids and 2 organophosphate insecticides have been documented (Rathman et al. 1990). The presence of *D. intermedius* in 2 of the 3 calendar sites suggests that it may also be developing resistance to these insecticides.

Significantly fewer parasitoid species were observed in the calendar farms than in the nominal threshold or selective farms (t = -5.04; df = 5, P = 0.004; Table 2). Absence of many species such as *C. punctiventris* and *C. oscinidis* from the calendar farms suggests that these species were adversely affected by frequent insecticide applications. In addition, the diversity index of species in each of the calendar farms was significantly lower than in the nominal threshold or the selective farms (Table 2).

Percentage parasitism in Glenwood (calendar) climbed to a maximum of 38% or 0.5 parasitoids per leaflet by the end of the planting cycle (Fig. 2). Insecticide treatments were halted for 2 weeks at this site, which could have accounted for this increase. But, *D. begini* at this site was also shown to be resistant to concentrations below field rates of oxamyl and methomyl (Rathman et al. 1990). *Diglyphus begini* appeared to be suppressed initially by intensive applications of oxamyl, methomyl and esfenvalerate (Fig. 2). However, the 2 week break in applications may have allowed these populations to increase. Parasitism levels continued to rise despite 2 applications of esfenvalerate and methomyl in the final weeks, suggesting that resistant populations might have been present, although further work is needed to verify this result.

Interestingly, the farm with the highest diversity levels was Kealakekua, a nominal threshold site (Table 2), which restricted its use of broadly toxic insecticides to 3 applications in the first 3 weeks after planting (esfenvalerate, oxamyl and endosulfan), and 3 applications during harvest when whiteflies exceeded perceived economic levels. Leafminer parasitoids may have been able to survive this regime of applications, perhaps because residues of insecticides on the leaf surface had decreased to sublethal levels. Overall parasitism rates were fourfold higher in the nominal and selective farms than in the calendar farms (F = 11.95; df = 4, 54; P = 0.0001; Table 3). However, no differences in parasitism occurred between the nominal threshold and selective farms (Table 3).

In addition to the relatively high rates of leafminer parasitism observed in the

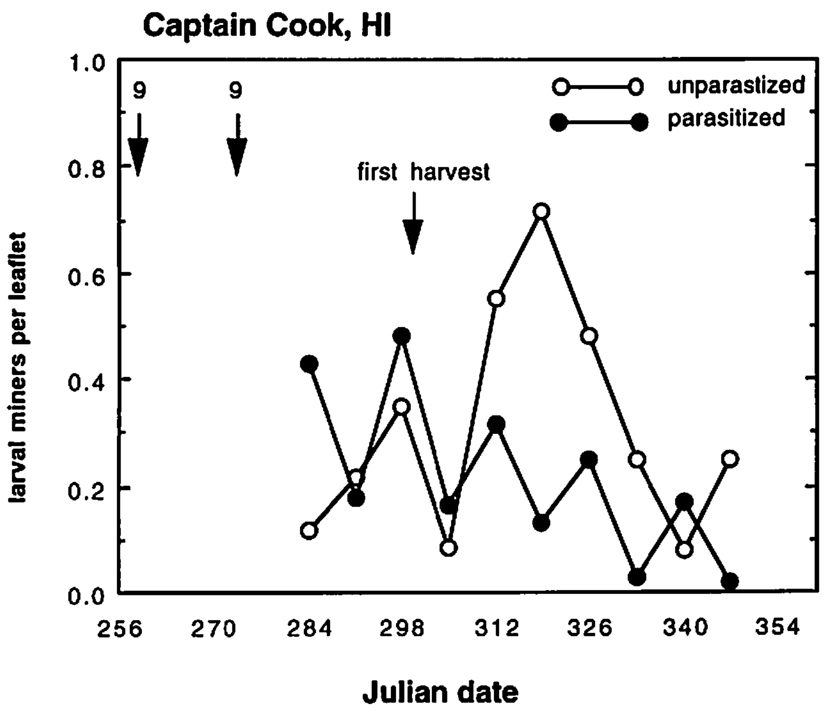

Fig. 3. Density of unparasitized (open circles) and parasitized (closed circles) leafminer larvae in Selective field. Arrows indicate times of insecticide application. 9 = *B. thuringiensis kurstaki* (Btk).

Captain Cook (selective) farm, large numbers of *Cyrtopeltis modestus* Distant were observed at this farm (Fig. 3). *Cyrtopeltis modestus* was sporadically observed in the Kealakekua farm, but was absent from the samples of the remaining 5 farms suggesting high susceptibility to insecticide applications. In the Captain Cook farm, *C. modestus* increased as the leafminer populations initially declined. These data suggest that *C. modestus* also contributed to mortality of the leafminer larvae. As a generalist predator, it probably does not discriminate between internally parasitized and unparasitized larvae; this could also account for mortality of parasitoids as well. In the Captain Cook farm, there did not appear to be a numerical response between parasitoids and larval leafminers. Perhaps *C. modestus* was reducing the impact of these parasitoids. There are no studies that document the impact of *C. modestus* on leafminer populations, but it has been reported as a facultative predator of leafminers in California (Parrella & Bethke 1982).

Whiteflies

The greenhouse whitefly, *Trialeurodes vaporariorum* (Westwood) was present in all farms (Fig. 4). In the Glenwood, Volcano, and Kealakekua farms, despite intensive insecticide use (up to 23 applications), whitefly populations exceeded economic injury levels for a 10 and 20% yield loss as defined by Johnson et al. (1992) for 2–8 weeks (Fig. 4). Other studies show that the greenhouse whitefly is resistant to several classes of insecticides and it is increasingly difficult to control whiteflies with chemicals (Omer et al. 1993). Whiteflies were practically absent in the Ho'olehua and Kula (900 m) farms, and thus are not included in Fig. 4.

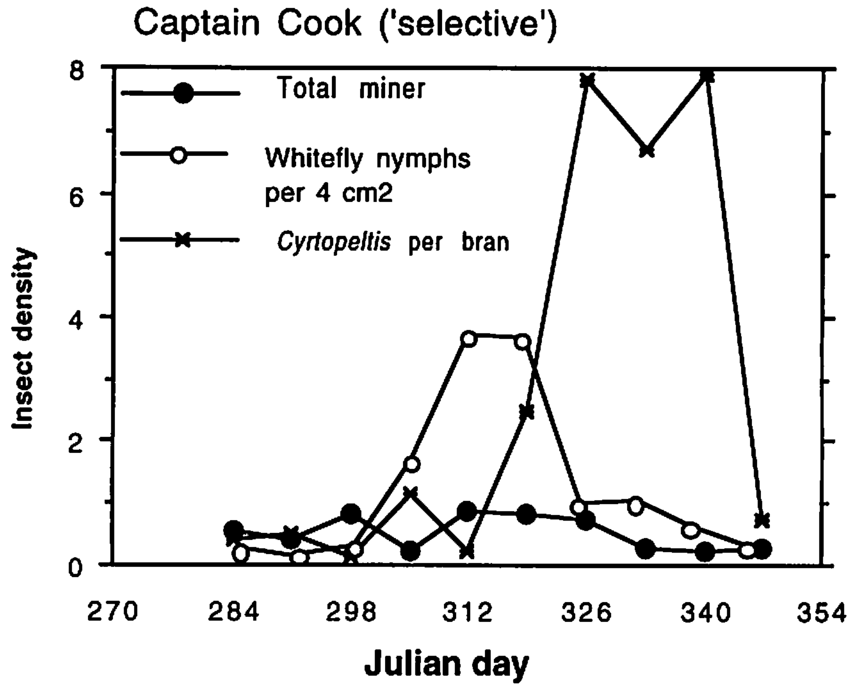

Fig. 4. Density of whitefly nymphs vs. density of *Cyrtopeltis modestus* (Captain Cook).

Table 4. Mean infestation of tomatoes by fruit pests at harvest.

		Mean Percent Infested Fruit[1]						
Pesticide use/Farm	No. Harvests	TPW	TFW	BAW	Total Leps	Fruit Fly stings	SGSB punctures	Total damage
Calendar:								
Glenwood	4	0.2	0.0	0.4	0.6	0.4	0.0	1.0
Volcano	4	0.0	0.4	0.2	0.6	0.0	0.0	0.6
Nominal:								
Kealakekua	7	0.2	0.8	0.0	1.1	0.1	3.3	4.5
Moloka'i	6	0.6	0.6	1.2	2.3	1.0	0.0	3.3
Kula 450m	4	3.1	8.9	1.7	13.8	0.6	0.0	14.4
Selective:								
Capt . Cook	8	0.0	2.4	0.2	2.6	0.0	7.8	7.8
Totals	33	4.1	13.1	3.7	21.0	2.1	11.1	

[1] TPW = Tomato pinworm, TFW = Tomato fruitworm, BAW = Beet armyworm, SGSB = southern green stink bug.

Whitefly densities in the selective farm in Captain Cook only slightly exceeded the 5% economic injury level for 2 weeks. Large populations of the predator, *C. modestus* may have helped regulate populations of the whiteflies in this farm (Fig. 4). Greenhouse whitefly numbers in the nominal threshold farm in the 2 Kula sites did not exceed the economic injury level, although *C. modestus* was absent from the samples, which suggests that *C. modestus* was susceptible to the materials applied.

In the Kealakekua site, at the time of first tomato harvest, the tomato disorder known as irregular ripening (IRR) (Schuster et al. 1990) was observed. This was the first time that this disorder had been reported in a tomato planting in Hawai'i. This tomato farm was adjacent to a mature cucumber field that reportedly contained large numbers of *B. tabaci* adults. The tilling of the cucumber field coincided with the appearance of *B. tabaci* in the tomato farm. Both greenhouse whiteflies and *B. tabaci* were observed in this farm although the relative percentages of each species were not ascertained (Fig. 4). Densities of immature whiteflies exceeded the 5% economic levels defined for the greenhouse whitefly (Johnson et al. 1992) for about 6 weeks (and above the 10% EIL for 2 weeks) despite several applications of fenvalerate, methomyl, insecticidal soap, oxamyl, and endosulfan. Approximately 75% of the tomato samples had symptoms of IRR, resulting in a complete rejection of the fruit by commodity buyers. The level of IRR declined to below 50% of the tomato samples by the end of the 6-week period indicating that reduction of *B. tabaci* with insecticides reduced incidence of IRR. These results are similar to findings of Schuster et al. (1990), which suggested IRR symptom severity was related to the density of *B. tabaci* and that the developing tomato fruit exhibited reduced symptoms when whitefly nymphs were eliminated by pesticide applications. Economic injury levels for *B. tabaci* are not yet available, however total counts of whitefly nymphs were 0.25 per cm^2 at the time that IRR symptoms were first observed on the majority of fruit, which indicates that very low densities of *B. tabaci* can induce this disorder. Costa et al. (1993) have since reported that the type B biotype of *B. tabaci* exists in Hawai'i, which may have been associated with IRR disorder in the Kealakekua farm.

Whitefly parasites were not found in whitefly pupae examined in this survey, indicating that parasites in commercial tomatoes may not be very common. Other studies indicate that parasites are more prevalent on weedy species (Gerling 1983), suggesting that whitefly parasites in Hawai'i do not sufficiently regulate whitefly populations in tomatoes. Lynch & Johnson (1991) have developed mass rearing techniques for *E. formosa* and demonstrated that augmentative releases of parasites significantly reduced greenhouse whitefly levels only when migrations from outlying areas did not occur. Thus, augmentation of this parasite might also be effective on a commercial basis, but only when isolated from other whitefly sources.

Fruit pests

Fruit damage was mainly caused by lepidopteran larvae (Table 4). Of these, tomato fruitworm and beet armyworm were very common, occurring in 5 of the 6 farms (83%), while tomato pinworm was present in 4 farms (67%). In the calendar farms, less than 1% of fruit was damaged, indicating that insecticides were controlling these insects. However, in the selective farm, less than 3% of the fruit exhibited worm damage, and *Bt* was the only insecticide used. The low damage levels may have been because this farm was relatively new (< 2 years old), and these species had not fully become established in this area. In addition, this farm was relatively isolated from other infestation sources. However, tomato fruitworm exceeded 2%, presumably because of corn planted adjacent to the tomatoes, which served as a possible reservoir for these pests. It appears that the timing of *Bt* applications in the first 3 weeks of the planting cycle was probably not sufficient to prevent damage from occurring at harvest.

Of the farms using nominal thresholds, control tactics against Lepidoptera were effective at 2 of the 3 sites. At Ho'olehua, lycopersilure appeared to control pinworm, however, an untreated area in this site was not available for comparison. In contrast, at the Kula 450 site, damage exceeded 13% by the 3 species (Table 4). Of these, tomato fruitworm was the most abundant. This site also had the highest fruit infestation by tomato pinworms of all farms surveyed. Populations reached a maximum of 57 moths per trap per day by the final harvest (Fig. 5), which exceeded density treatment levels for California pole tomatoes (35 moths per trap per day, University of California 1990). Inadequate coverage of insecticides and poor timing of controls may have accounted for the high level of pinworm damage at this site.

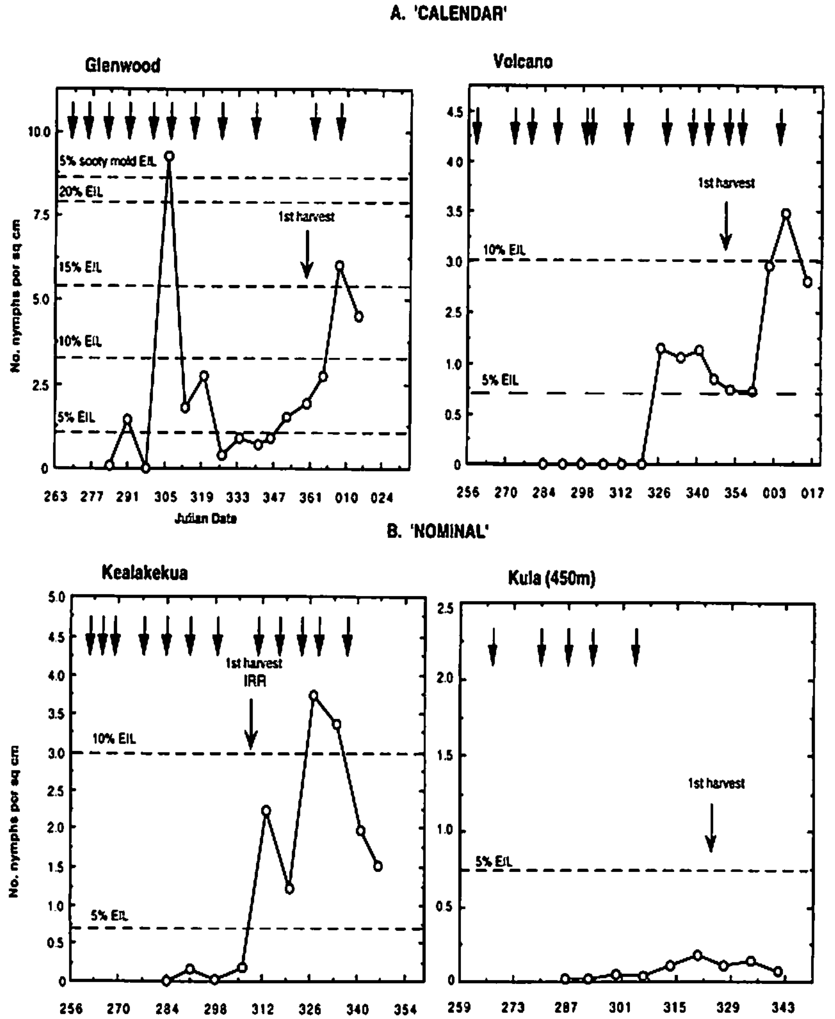

Fig. 5. Foliage densities of whitefly nymphs in A) calendar and B) nominal threshold tomato farms. EIL = economic injury level for greenhouse whitefly. IRR = Irregular Ripening Disorder. Arrows indicate dates of insecticide sprays.

A significant positive relationship was observed between number of male pinworm moths per day in pheromone traps and the percentage of fruit infested with pinworm larvac ($r^2 = 0.86$; df = 4, $P \leq 0.05$). However, we consider this to be preliminary data, because 5 of the 6 farms had negligible trap populations (Fig. 5). We believe that pheromone traps for pinworm would be most effective for monitoring the initiation of flight periods. Prediction of larval damage with the traps could be a risk most farmers are unwilling to take, since the damage may occur at the same time or shortly after the moths are detected. However, a 3–4 month host-free period may be necessary before tomato planting to accurately target the starting point of population increase (University of California 1990). This could pose a limitation for some farmers in Hawai'i and other tropical areas because tomatoes can be planted continuously throughout the year, with little or no break between cropping periods.

The wing-style traps were not effective for monitoring tomato fruitworm populations. Less than 4 moths were trapped during the entire planting cycle in all farms combined. It has been reported that this style of trap is difficult for larger moths to enter and that the conical style *Heliothis* trap (Ecogen Inc. (formerly Scentry), Goodyear, AZ) is more effective (Hoffman et al. 1986). Relatively low levels of beet armyworm populations were observed in pheromone traps (never exceeding 10 moths per trap per day) and trap numbers did not significantly explain levels of fruit infestation ($r^2 = 0.019$, df = 31, $P = 0.443$).

Southern green stink bug punctures were only observed in the Kealakekua and Captain Cook farms although nymphs or adults were not found in the beating tray samples. The absence of this species in the calendar farms suggests that they were controlled by insecticides. Fruit with melon fly stings were apparent in 4 of the 6 farms. Levels were below 1% indicating that melon fly was susceptible to insecticides. Treatment of border vegetation in the Ho'olehua farm appeared to be effective. This tactic helped reduce the level of toxic sprays to the tomato crop.

Based on these results, we know that the primary fruit pests of tomatoes in Hawai'i are the tomato fruitworm and pinworm. Since infestation levels must be kept well below 5% at harvest to be commercially acceptable (Hawai'i Department of Agriculture 1981), growers tend to rely heavily upon insecticides for control of these pests. Farms that applied insecticides on a calendar basis controlled the fruit pests, but we do not consider it a successful management program, because outbreaks of whitefly and leafminer occurred. The use of nominal thresholds was generally as effective against these pests. We encourage the use of the most selective materials available, so that leafminer parasitoids and natural enemies are preserved. In addition, if *B. tabaci* is present, alternative tactics may be necessary, such as row covers (Costa et al. 1994) or shade cloths, which are impermeable to whiteflies. The selective tactic was generally as successful as the nominal use strategy. However, this was probably because population densities of worms and fruit flies were relatively low.

If growers want to reduce the high cost of spraying insecticides and avoid unnecessary applications that are environmentally disruptive, then monitoring for these pests is essential. Although economically difficult for small growers in Hawai'i to employ a trained field scout, sampling pests such as leafminers and whiteflies could assist growers in making intelligent management decisions. Therefore, rapid yet effective sampling methods such as the presence/absence technique Johnson et al. (1991) developed for greenhouse whitefly would be particularly useful to growers in Hawai'i.

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