Use of Attractants to Suppress Oriental Fruit Fly and *Cryptophlebia* spp. in Litchi

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Abstract. Litchi (*Litchi chinensis* Sonn.) is subject to damage by a range of insect pests, the most important of which are the oriental fruit fly, *Bactrocera dorsalis* (Hendel) (Diptera: Tephritidae), the koa seedworm, *Cryptophlebia illepida* (Butler), and the litchi fruitmoth, *C. ombrodelta* (Lower) (also known as the macadamia nut borer) (Lepidoptera: Tortricidae). The activity of tephritid fruit flies and *Cryptophlebia* spp. (hereafter referred to as *Cryptophlebia*) both can lead to several types of fruit defects, including holes, stains, and release of fruit juices, making it difficult to distinguish which pest caused the damage. Field studies were conducted to minimize the occurrence of these types of fruit defects through use of a spinosad-based protein bait (GF-120 Fruit Fly Bait) to suppress oriental fruit fly populations, and an attractant associated with a contact insecticide (attract-and-kill) technique (Last Call) to suppress *Cryptophlebia* populations in litchi orchards at the scale of individual farms. The Last Call product used was based on a pheromone blend developed for the macadamia nut borer because preliminary tests identified that this blend was more attractive to both *C. ombrodelta* and *C. illepida* than was a pheromone blend developed for the oriental fruit moth, *Grapholita molesta* (Busck). Overall, based on results from four split plot litchi orchards, there was no significant difference in oriental fruit fly trap catch between spray and control sections at any trap service date. However, population reduction in the sprayed section of one orchard with a higher *B. dorsalis* population may have been a result of the spray application. *Cryptophlebia* trap catch was significantly lower in the treated orchards after the first Last Call application. *Cryptophlebia* infestation was more than three-fold greater than infestation by oriental fruit fly in each of the orchards. For both pests, there was no significant difference in infestation rate or infestation-related fruit damage between control and treatment orchards. Improved bait sprays and improved attract-and-kill products and/or larger treatment areas may be needed to provide satisfactory levels of fruit fly and *Cryptophlebia* suppression.

Key words: attract-and-kill, *Cryptophlebia ombrodelta*, *Cryptophlebia illepida*, *Bactrocera dorsalis*, spinosad, Tephritidae, Tortricidae

Introduction

Litchi (*Litchi chinensis* Sonn.) is a tropical specialty fruit in Hawaii which has shown a steady increase in acreage planted in recent years. The most important insect pests are tephritid fruit flies, principally oriental fruit fly, *Bactrocera dorsalis* (Hendel) (Diptera: Tephritidae), koa seedworm, *Cryptophlebia illepida* (Butler), and litchi fruitmoth, *C. ombrodelta* (Lower) (Lepidoptera: Tortricidae) (Follett et al. 2003). The activity of tephritid fruit flies and *Cryptophlebia* spp. (hereafter referred to as *Cryptophlebia*) can lead to several types of fruit defects, including holes, stains, and release of fruit juices. Since there is an overlap in the damages occurring as a result of these two groups of pests, we chose to conduct a combined suppression trial against both groups. The methods of pest suppression for both groups utilized products which included an attractant associated with a toxicant, but different products were used for each pest group. For tephritid fruit fly suppression we applied GF-120 Fruit Fly Bait (Dow Agrosciences LLC, Indianapolis, IN), a spinosad-based bait spray recently commercialized for use in Hawaii. Spinosad-based baits have been effective against Mediterranean fruit fly (lab: Vargas et al. 2002, Adan et al. 1996; field: McQuate et al. 2005b, Burns et al. 2001, Peck and McQuate 2000) and melon fly (field: Prokopy et al. 2003). Effectiveness in the field of spinosad-based baits against oriental fruit fly has not yet been documented in the literature, though lab studies have suggested that they should be effective (McQuate et al. 2005a; Stark et al. 2004).

For *Cryptophlebia* suppression, we used an experimental Last Call (IPM Technologies, Portland, OR) attract-and-kill product. Attract-and-kill products have shown promise for control of several tortricid pests including codling moth, *Cydia pomonella* (L.) (Charmillot et al. 2000), lightbrown apple moth, *Epiphyas postvittana* (Walker) (Suckling and Brockerhoff 1999), and pink bollworm, *Pectinophora gossypiella* (Saunders) (Hofer and Angst 1995). Charmillot et al. (2000) consider attract-and-kill technology superior to mating disruption for small farms and in areas with high winds and trees grown on slopes, all of which are characteristics of Hawaii's litchi orchards. Identifying an attractive sex pheromone is the first step in developing an effective attract-and-kill product for koa seedworm and litchi fruitmoth in Hawaii. When properly formulated, attracticide droplets can be more attractive to male moths than calling female moths (Krupke et al. 2002). Chang (1995) demonstrated that the commercial oriental fruit moth pheromone blend of 93% *Z*8-12:Ac, 4% *E*8-12:Ac, 1% *Z*8-12:OH, and 2% *Z*7-12:Ac is attractive to *Cryptophlebia* in Hawaii. Oriental fruit moth, (OFM), *Grapholita molesta* (Busck) (Lepidoptera: Tortricidae), pheromone has been used in attempts at mating disruption for *Cryptophlebia* in macadamia (V. Jones unpublished). Recently a new pheromone blend was developed by the Commonwealth Scientific and Industrial Research Organisation (CSIRO) for *Cryptophlebia ombrodelta* (also known as the macadamia nut borer [MNB]). IPM Technologies (Portland, OR) formulated the MNB pheromone into an experimental Last Call attract-and-kill product. The purpose of this study was first to compare the attractiveness of the MNB pheromone with the OFM pheromone to *Cryptophlebia* spp. in Hawaii. Second, this study tested the efficacy of Last Call MNB and GF-120 Fruit Fly Bait spray for suppression of *Cryptophlebia* and oriental fruit fly, respectively, in litchi at the scale of individual farms.

Materials and Methods

***Cryptophlebia* Pheromone Study.** The test comparing the attractiveness of the CSIRO MNB pheromone blend and the OFM blend (IPM Technologies, Portland, OR) was conducted in a macadamia nut orchard known to support *Cryptophlebia* populations in Kapaau, HI, in July–August 2002. Approximately 320 ha of contiguous macadamia nut orchards are located in this area. Macadamia nuts are harvested during 8 months from April–May to January–February, and *Cryptophlebia* can be trapped throughout the year, although distinct peaks occur (Jones 2002). Four groups of three neighboring trees were selected in a 4.0 ha block near the center of the area. Trees (a mix of cultivars 344, 246, and 508) were 25 years old, approximately 6.0 m in height, and spaced 4.5 x 9.0 m. Each group of trees was separated by a minimum of four rows and a distance of 60 m. Each tree in a group was randomly selected to receive either MNB pheromone blend, OFM pheromone blend, or a control trap with no lures. Each pheromone blend was loaded onto separate rubber septa at a rate of 10 mg per septum at IPM Technologies (Portland, OR). Pheromone lures applied to rubber septa were placed in delta traps (Scenturion Inc. Guardpost LPD, Clinton, WA) suspended

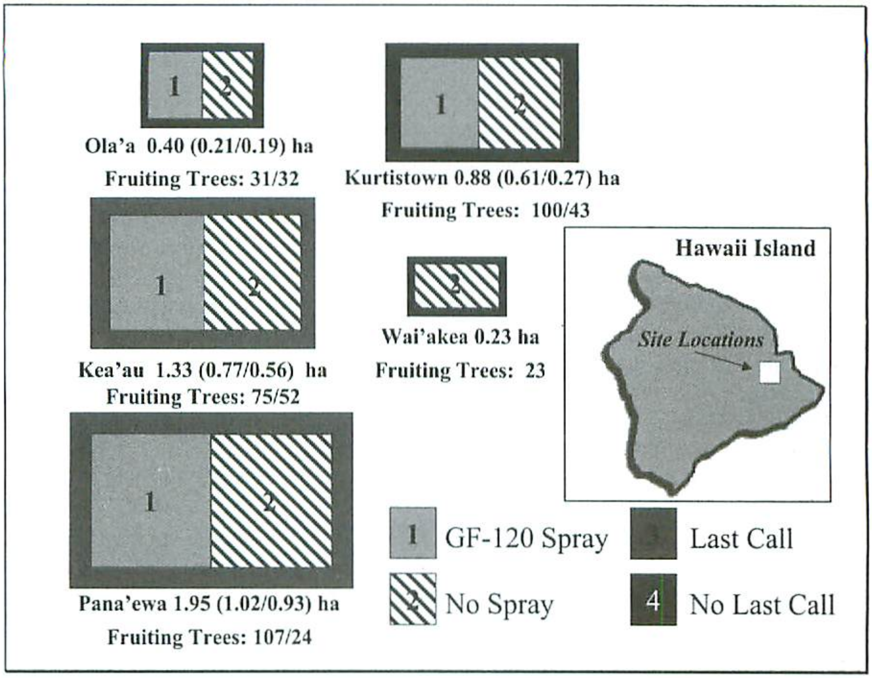

Figure 1. Site location of trials and assignment of treatments to orchards. Overall orchard area, followed by the split between the area sprayed by GF-120 and the area unsprayed and the numbers of fruiting trees in each section (area sprayed/area unsprayed) is indicated for each orchard. Overall sizes of the rectangles representing the orchards are proportional to the actual orchard areas.

from branch tips within the row at eye height and moth catch was recorded after two weeks. The experiment was repeated on two dates, two weeks apart.

Study Sites for Suppression Trials. The suppression study was conducted in five litchi orchards on Hawaii island (Fig. 1): a 2.8 ha orchard in Panaewa, a 0.6 ha orchard in Keaau, a 1.2 ha orchard in Kurtistown, a 0.4 ha orchard in Olaa and a 0.3 ha orchard at the Waiakea Agricultural Research Station on the island of Hawaii. These orchards reflect the variability in size of litchi orchards in Hawaii. The orchards ranged from 70 – 250 m in elevation. The cultivar Kaimana was planted in all orchards. The Kurtistown orchard also included the cultivars Bosworth and Groff; however, these cultivars bore fruit later in the season than Kaimana and the study was terminated before these fruits ripened. Fruit set varied among the orchards, with 75%, 89%, 95%, 21% and 62% of trees bearing fruits in the Keaau, Kurtistown, Olaa, Panaewa and Waiakea orchards, respectively. Moth pheromones are long range attractants whereas fruit fly baits are short distance attractants. For this reason we chose to use a split plot with fruit fly bait sprays and whole orchards for Last Call attract and kill applications against *Cryptophlebia*. The idea with attract and kill is to eliminate all males from the resident and immigrating population. This is best done by treating whole, isolated orchards. Our choice of orchards to treat for *Cryptophlebia* was based on isolation from good hosts outside the orchard (that might supply moths) rather than size or other characteristics.

Insect Population Monitoring. *Fruit Fly Populations.* Fruit fly populations were monitored using yellow bottom plastic dome traps (Biosys, Inc., Palo Alto, CA, U.S.A.) baited with a mixture of 8.0% (w/w) Solulys AST (Roquette America, Inc., Keokuk, IA), 4.0% (w/w) borax, and 88.0% (w/w) water. Traps were deployed on 25 April, 2003, at least two weeks before the first spray and the first litchi fruit harvests in any of the orchards. Six traps were placed in each control section and six traps were placed in each treatment section of each orchard (see below) and were serviced weekly until 2 July, 2003.

Cryptophlebia Populations. Cryptophlebia populations were monitored using delta traps containing CSIRO macadamia nut borer lures (IPM Technologies, Portland, OR), with three traps per block. Traps were serviced every two weeks. Trap monitoring was begun earlier in lower elevation orchards (Panaewa and Waiakea), resulting in one additional trap service for these orchards compared to the other three orchards. Recovered moths were identified to species using size differences and distinguishing hind leg characteristics (Jones 2002). Voucher specimens were confirmed by Dr. John Brown at the USDA Systematic Entomology Laboratory, Beltsville, MD.

Treatments. *Bait Spray for Fruit Fly Suppression.* Each of four orchards (Keaau, Kurtistown, Olaa, and Panaewa) was subdivided into treatment (sprayed) and control (unsprayed) sections as indicated in Fig. 1. In all cases there was some separation between these two sections. Typically, they were separated by a road with or without windbreak trees. The bait spray used was GF-120 Fruit Fly Bait (Dow Agrosciences LLC, Indianapolis, IN). The spray was applied as spots on the underside of the litchi tree leaves at a rate of 3.9 liters of diluted product (prepared according to label directions) per hectare. Fruiting trees received multiple spots, with more spots applied to larger trees and trees with more fruits. Nonfruiting trees were also treated, but at a lower rate, with only one spot applied per tree for smaller trees. This application approach was used so that the bait was applied preferentially near ripe fruits where higher densities of flies were expected. Bait sprays were applied once a week starting before the first fruit harvest.

Attract-and-kill for Cryptophlebia. Two orchards (Keaau and Panaewa) were treated with the Last Call® MNB attract-and-kill formulation (IPM Technologies, Portland, OR) at monthly intervals throughout the fruit development period. The treatment interval selected was in line with the manufacturer's recommendation (4–6 weeks), based on research with codling moth (Charmillot et al. 2000). The Keaau orchard was treated on 13 May and 17 June, 2003. The Panaewa orchard was treated on 9 May and 13 June, 2003. Last Call incorporates a *Cryptophlebia* sex pheromone (0.16%) and insecticide (permethrin, 6.0%) in a waterproof gel carrier and was applied to orchards at a rate of 1200, 50 μl droplets per acre (13 droplets per tree). The pheromone concentration was chosen by the manufacturer based on research with codling moth (Charmillot et al. 2000). Three other orchards within a 10 km radius (Kurtistown, Olaa and Waiakea) were used as untreated control orchards (see Fig. 1).

Assessment of Infestation and Fruit Damage. Every two weeks throughout the fruiting season (8 May–24 June, 2003), 100 ripe fruits were collected from each section of each orchard. Fruits were weighed and then assessed visually for the presence on the fruit surface of cracks, holes, juice, stains and *Cryptophlebia* eggs or larvae. Fruits were then opened and searched visually for the presence of any fruit fly eggs. In order to identify the species of fruit fly, all recovered fruit fly eggs were placed on sections of ripe papaya and held in screen topped buckets with sand on the bottom to serve as a pupation medium. After two weeks, the sand was sieved for collection of any pupae. The pupae were then transferred to small screen-topped containers holding only sand and any emerged adults were identified to species.

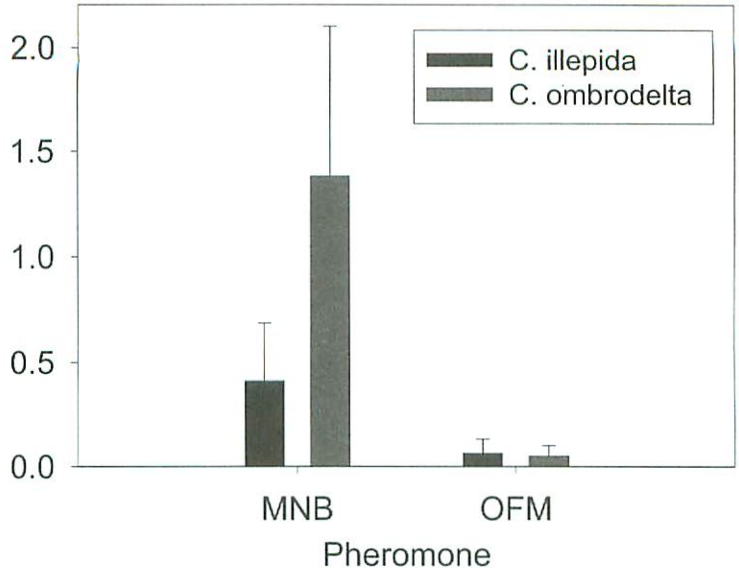

Figure 2. Average catch per trap per day of *C. illepida* and *C. ombrodelta* in delta traps baited with either CSIRO-formulated macadamia nut borer (MNB) pheromone blend or oriental fruit moth (OFM) blend.

Statistical Analyses. Comparison of fruit fly population levels between sprayed and control orchard sections (fruit fly suppression test) was made using paired t-tests of $\log_{10}$ transformed [$\log_{10}$ (10x + 1)] (Sokal and Rohlf 1981) trap catch results. Because three of the orchards had very low oriental fruit fly populations, so there was little potential for impact of the bait sprays, separate *t*-tests of $\log_{10}$ transformed trap catch results were also calculated for the Panaewa Orchard where oriental fruit fly populations were higher. Comparison of *Cryptophlebia* population levels between sprayed and control orchards (*Cryptophlebia* suppression test) was made using t-tests of $\log_{10}$ transformed [$\log_{10}$ (10x + 1)] combined species trap catch results (SPSS Inc. 2000). Comparison of percentage infestation by oriental fruit fly and fruit damage between sprayed and control orchard sections was made using paired t-tests of arcsin transformed (arcsin[sqrt[proportion damaged]]) proportion damaged data, using different sample dates as replicates. Comparison of percentage *Cryptophlebia* infestation and fruit damage between Last Call treated and control orchards was made using t-tests of arcsin transformed proportion damaged results (arcsin[sqrt[proportion damaged]]).

Results

***Cryptophlebia* Pheromone Study.** The trap catch data for the first and second week were not significantly different so both weeks were combined for further analysis. The MNB lure caught significantly more *C. ombrodelta* than the OFM lure (1.4 vs. 0.05 moths per trap per day) ($t = 5.2$, df = 7.1, P = 0.001). The MNB lure also caught significantly more *C. illepida* than the OFM lure (0.4 vs. 0.06 moths per trap per day) ($t = 3.4$, df = 7.9, P = 0.009) (Fig. 2).

Insect Populations. *Fruit Flies.* Average trap catch in spray and control sections of each orchard at each trap servicing date is presented in Table 1. Although no bait sprays were

Table 1. Mean total oriental fruit fly trap catch ([males + females] per trap per day) (± SEM) in sprayed and control sections of four litchi orchards. No sprays were applied in the fifth orchard (Waiakea) but trap catch data is included here for comparison because the highest trap catches of the study overall were recorded there.

		Weeks pre-spray		Weeks post-initiation of weekly sprays					
Orchard	Treatment	1	2	1	2	3	4	5	6
Keaau	Spray	0.05(0.05)	0.00(0.00)	0.00(0.00)	0.00(0.00)	0.00(0.00)	0.02(0.02)	0.00(0.00)	0.00(0.00)
	Control	0.00(0.00)	0.00(0.00)	0.06(0.03)	0.02(0.02)	0.06(0.03)	0.02(0.02)	0.12(0.09)	0.02(0.02)
Kurtistown	Spray	0.24(0.14)	0.22(0.16)	0.03(0.02)	0.00(0.00)	0.03(0.02)	0.02(0.02)	0.07(0.03)	0.07(0.07)
	Control	0.26(0.09)	0.28(0.11)	0.03(0.02)	0.05(0.03)	0.06(0.03)	0.04(0.05)	0.05(0.05)	0.00(0.00)
Olaa	Spray	0.36(0.13)	0.03(0.02)	0.00(0.00)	0.00(0.00)	0.03(0.02)	0.04(0.05)	0.02(0.02)	0.10(0.06)
	Control	0.05(0.05)	0.08(0.03)	0.00(0.00)	0.00(0.00)	0.03(0.02)	0.15(0.11)	0.07(0.03)	0.02(0.02)
Panaewa	Spray	0.38(0.19)	1.53(0.45)	0.94(0.16)	0.71(0.28)	0.56(0.24)	0.35(0.14)	0.31(0.14)	0.10(0.05)
	Control	0.71(0.35)	1.56(0.34)	1.11(0.21)	1.07(0.23)	1.17(0.24)	1.21(0.28)	1.33(0.32)	0.62(0.23)
Waiakea	Control	0.07(0.05)	0.08(0.03)	0.00(0.00)	0.26(0.11)	0.08(0.05)	1.85(0.64)	3.36(0.55)	2.05(0.40)

Table 2. Mean trap catch (moths per trap per day) (± SEM) of male *Cryptophlebia* in control litchi orchards and orchards treated with Last Call.

Orchard	Treatment	Pre-treatment	Weeks post-treatment		
			2	4	6
Keaau	Last Call	2.35 (0.18)	0.17 (0.11)	0.17 (0.04)	—
Kurtistown	Control	1.62 (0.20)	1.02 (0.15)	1.50 (0.60)	—
Olaa	Control	0.43 (0.04)	0.27 (0.12)	0.50 (0.06)	—
Panaewa	Last Call	4.07 (1.23)	0.00 (0.00)	0.05 (0.05)	0.13 (0.07)
Waiakea	Control	0.57 (0.14)	0.07 (0.07)	0.72 (0.23)	0.46 (0.11)

applied in the Waiakea orchard, so this orchard had no paired treatment/control subsections, trap catch data is also included from this orchard in the table because it documents the highest oriental fruit fly populations recorded in the course of the study. For all four orchards considered together, there was no significant difference in oriental fruit fly trap catch between spray and control sections at any trap service date. At three of the sites (Keaau, Kurtistown, and Olaa) oriental fruit fly populations were low throughout the study. From the time of the first harvest until the end of the trial, oriental fruit fly trap catch was no higher than 0.15 flies/trap/day in any control or bait-treated section in the three orchards. The oriental fruit fly populations in the Panaewa and Waiakea orchards, however, were considerably higher than in the other three orchards. After the first spray in the Panaewa orchard, average trap catch in the sprayed section was lower than in the control section on all dates, with catch significantly less at week 6 ($t = 3.299$, df = 9.3, $P = 0.009$) and week 7 ($t = 3.328$, df = 8.7, $P = 0.009$) (Fig. 3). Average trap catch in the Waiakea orchard was less than 0.30 flies per trap per day through week 5, but then increased considerably at the end of the season reaching 1.9 (week 6), 3.4 (week 7) and 2.1 flies per trap per day (week 8).

Cryptophlebia. Pre-treatment and post-treatment trap catch in each of the orchards is presented in Table 2. The proportion of each *Cryptophlebia* species varied widely among trap recoveries. The proportion of *C. ombrodelta* ranged from 0 to 100%, with an average of 33.9%. There was no significant pre-treatment difference in trap catch of total moths in control orchards versus orchards treated with Last Call ($t = 1.42$, df = 1, $P = 0.39$). However, significantly fewer moths were caught in the treated orchards two weeks after the initial treatment with Last Call ($t = -21.94$, df = 1, $P = 0.03$). At four weeks, trap catch in the treated orchards was numerically less than in the control orchards, but the difference was not statistically significant ($t = -7.66$, df = 1, $P = 0.08$).

Infestation. *Fruit Flies*. Table 3 summarizes the oriental fruit fly infestation in the litchi fruits collected at each of the orchards. There was, overall, no significant difference in infestation rate between sprayed and control sections of each of the four orchards. Infestation rate was generally low. The maximum infestation rate in any of the orchards with the split spray/control sections was 3.8%, found in the last fruit collection at the Pana'ewa orchard. This was also the orchard (among those with the split spray/control sections) that

Table 3. Total fruits collected, average (±SEM) percentage oriental fruit fly infestation and number of eggs recovered in ripe litchi fruit samples collected from both treated and control sections of four orchards and a fifth "control only" orchard.

Orchard	Treatment	No. collections	Total no. fruits collected	No. fruits infested	% fruits infested	No. eggs	Eggs per infested fruit
Keaau	Spray	3	315	1	0.32 (0.32)	10	10
Keaau	Control	3	325	0	0.00 (0.00)	0	—
Kurtistown	Spray–prespray	1	103	0	0.00	0	—
Kurtistown	Control–prespray	1	100	0	0.00	0	—
Kurtistown	Spray	3	305	1	0.33 (0.33)	0	—
Kurtistown	Control	3	311	0	0.00 (0.00)	0	—
Olaa	Spray–prespray	1	96	0	0.00	0	—
Olaa	Control–prespray	1	117	1	0.85	4	4
Olaa	Spray	3	308	6	1.95 (0.56)	57	9.5
Olaa	Control	3	306	3	0.97 (0.55)	20	6.7
Panaewa	Prespray	1	214	7	3.27	45	6.4
Panaewa	Spray	3	325	10	3.10 (1.69)	51	5.1
Panaewa	Control	3	314	12	3.82 (1.47)	150	12.5
Waiakea	Control	3	312	27	8.65 (3.89)	355	13.1

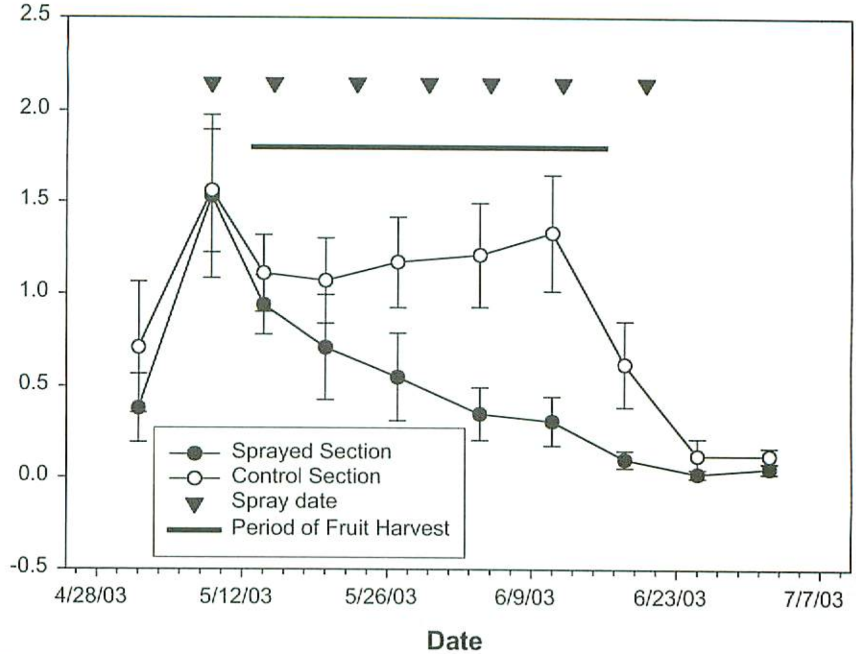

Figure 3. Average total (male + female) oriental fruit flies per trap per day in protein bait traps in the sprayed versus the control sections of the Panaewa litchi orchard.

had the highest oriental fruit fly population based on trap catches. A higher infestation rate (8.7% overall; 15.4% in the last collection) was found at the Waiakea control orchard. Increased infestation rate over time was found only in the Waiakea control orchard where the infestation rate increased at the end of the fruiting season from 1.92% (29 May, 2003) to 8.65% (5 June, 2003) to 15.38% (25 June, 2004). Of the total of 693 fruit fly eggs recovered from the litchi fruits from all sites combined, 44.9% (311) developed to the adult stage and all were found to be oriental fruit flies.

Cryptophlebia. *Cryptophlebia* infestation in the litchi fruits collected at each of the orchards ranged from 5.78 to 26.6% (Table 4). *Cryptophlebia* infestation was at least threefold higher than infestation by oriental fruit fly in each of the orchards. Overall there were no significant differences in *Cryptophlebia* infestation rates between treated and control orchards at any of the collection times. The highest *Cryptophlebia* infestation rates were found in the Panaewa orchard (17.7%),which received Last Call treatments, and the untreated Waiakea orchard (26.6% overall; 37.1% in the first collection).

Fruit Damage. Table 5 summarizes the occurrence of fruit defects in the sampled fruits that could relate to damage by fruit flies and/or *Cryptophlebia*. There was no significant difference in any of the defects in the sprayed versus control orchard sections or in orchards treated with Last Call versus untreated orchards. The most common defect was the presence of a stain on the fruit. This defect was present on 6.5–20.8% of the fruit across all orchards. All defects were most prevalent in the Waiakea orchard, which had the highest population of oriental fruit fly and the highest infestation rates of both oriental fruit fly and *Cryptophlebia*.

Table 4. Average (± SEM) *Cryptophlebia* infestation in litchi fruit samples collected from treated and control orchards.

Orchard	Treatment	No. collections	Total no. fruits collected	No. fruits infested	Avg. % fruits infested	No. eggs	Eggs per infested fruit
Keaau	Last Call	3	640	37	5.80 (0.75)	48	1.30
Kurtistown	Control	4	819	75	9.13 (1.31)	103	1.39
Olaa	Control	4	827	91	10.68 (2.60)	114	1.31
Panaewa	Pre-Treatment	1	224	45	20.09	58	1.29
Panaewa	Last Call	3	639	113	17.29 (2.31)	129	1.22
Waiakea	Control	3	312	83	26.48 (5.58)	109	1.33

Table 5. Occurrence of fruit defects in fruit samples from both control and treatment sections of each of four litchi orchards. Combined totals of defects in spray and control sections of each orchard, plus the defect totals from a fifth orchard, are also presented because the *Cryptophlebia* treatment was based on whole orchards. None of the differences in defects between the spray and control orchard sections (fruit fly test) or the Last Call-treated and control orchards (*Cryptophlebia* test) were significant at the $\alpha = 0.05$ level.

		Total no.	Number(%) of fruits with indicated defect			
Orchard	Section	of fruits	Cracks	Holes	Juice	Stain
Keaau	Spray (Fruit Fly)	315	1 (0.3%)	25 (7.9%)	21 (6.7%)	32 (10.2%)
Keaau	Control (Fruit Fly)	325	7 (2.2%)	6 (1.8%)	10 (3.1%)	21 (6.5%)
Keaau	Total (Last Call)	640	8 (1.2%)	31 (4.8%)	31 (4.8%)	53 (8.3%)
Kurtistown	Spray (Fruit Fly)	408	5 (1.2%)	15 (3.7%)	9 (2.2%)	66 (16.2%)
Kurtistown	Control (Fruit Fly)	411	8 (1.9%)	25 (6.1%)	15 (3.6%)	53 (12.9%)
Kurtistown	Total (Control)	819	13 (1.6%)	40 (4.9%)	24 (2.9%)	119 (14.5%)
Olaa	Spray (Fruit Fly)	404	11 (2.7%)	27 (6.7%)	26 (6.4%)	51 (12.6%)
Olaa	Control (Fruit Fly)	423	11 (2.6%)	22 (5.2%)	25 (5.9%)	51 (12.1%)
Olaa	Total (Control)	827	22 (2.7%)	49 (5.9%)	51 (6.2%)	102 (12.3%)
Panaewa	Spray (Fruit Fly)	322	6 (1.9%)	25 (7.8%)	14 (4.3%)	67 (20.8%)
Panaewa	Control (Fruit Fly)	535	10 (1.9%)	34 (6.4%)	23 (4.3%)	72 (13.5%)
Panaewa	Total (Last Call)	857	16 (1.9%)	59 (6.9%)	37 (4.3%)	139 (16.2%)
Waiakea	Total (Control)	312	11 (3.5%)	44 (14.1%)	34 (10.9%)	79 (25.3%)

Discussion

Although infestation by oriental fruit flies reached over 15% by the end of the season in one orchard (third fruit collection at Waiakea Orchard), infestation was low in most litchi orchards. The application of the bait spray seemed to reduce the fruit fly population in an orchard with higher fruit fly populations (Panaewa), but a reduction in fruit infestation was not found. Given the known mobility of fruit flies, better suppression of population levels and fruit infestation rates may have been generated through full orchard sprays rather than through the half orchard sprays used in this study. However, splitting each orchard into spray and control sections was necessary in order to establish suitable control sections because of the variability among orchards in fruit fly population levels. Overall, it is clear that application of fruit fly bait sprays to litchi orchards is not needed under conditions of low oriental fruit fly population, which often may be the case (e.g. in the Keaau, Kurtistown, and Olaa orchards), because there is a low infestation rate under these conditions. At higher population levels (e.g., in the Panaewa Orchard), there may be a need to suppress the fruit fly population in order to minimize infestation and damage. Although the oriental fruit fly trap catch was significantly lower in the sprayed section of this orchard than in the unsprayed section at weeks 6 and 7, the lack of replicated sites having higher population levels limits the ability to extrapolate these results to other systems (McQuate et al. 2005b, Cottenie and De Meester 2003, Oksanen 2001). Even if the difference in trap catch between sprayed and unsprayed sections of the Pana'ewa orchard is a result of the bait spray application, the observed effect is less than that observed for Mediterranean fruit fly where application of GF-120 Fruit Fly Bait in coffee led to significant differences in trap catch one week after the first bait spray application and significant differences in infestation rate within 4 weeks of the first bait spray application (McQuate et al. 2005b). Although lab studies have shown spinosad to be an effective toxicant for oriental fruit fly (McQuate et al. 2005a, Stark et al. 2004), the bait used in GF-120 Fruit Fly Bait may need to be improved to increase effectiveness against oriental fruit fly. Field attractancy tests with wild flies in papaya orchards (GTM, unpublished data) have shown poor "distance attraction" of GF-120 Fruit Fly Bait relative to established pH-adjusted protein baits like NuLure (Miller Chemical and Fertilizer, Hanover, PA), Solulys, and torula yeast tablets (ERA International Ltd., Freeport, NY). Good attraction is critical for the effectiveness of GF-120 because the application rates permitted by the supplemental labeling of the 24(c) Special Local Need Registration in Hawaii (2 to 4 liters/ha) are too low to permit complete coverage in an orchard situation. Effectiveness of the product, when applied as scattered spots, requires that the flies are attracted to the spots and then feed on them.

In most orchards, fruit fly population and infestation rate didn't increase over the course of the season. There is little likelihood of in-orchard population build-up based on early season litchi infestation both because the litchi fruiting season is short and because litchi is a poor host for oriental fruit fly. The poor host status of litchi was observed in an earlier study (GTM unpublished data) where 35,722 ripe fruits were collected from the islands of Hawaii and Kauai over two years (1994 – 1995) and held for assessment of infestation by internal feeding pests. Average infestation of litchi fruits by oriental fruit fly was 0.23% across all 6 cultivars collected and 0.61% (53 out of 8649) for the Kaimana fruits included in the 35,722 fruits. Lacking in-orchard population sources, oriental fruit fly population increases must come from immigration from other hosts outside the litchi orchard. Consequently, the level of damage of litchi fruit by oriental fruit fly will be influenced by the presence or absence of adjacent alternate host trees. Oriental fruit fly has an extensive host range (White and Elson-Harris 1992) and agricultural diversification in Hawaii, both commercially and in residential neighborhoods, can provide many alternate hosts, the infestation of which can contribute to area fruit fly populations.

In addition to the concern that oriental fruit flies immigrate from other host areas, there is an additional concern that immigrating flies may not adequately respond to protein baits applied in the litchi orchards. If the response of oriental fruit flies to GF-120 Fruit Fly bait is comparable to the response by melon flies, females that carry mature eggs and have had adequate recent protein consumption may bypass the bait and go directly to the ripe fruits (Prokopy et al. 2003). In this case, suppression of infestation may best be accomplished by bait spray applications in the source population, rather than through bait sprays in the litchi orchard, similar to the reduction of Mediterranean fruit fly (*Ceratitis capitata* (Wiedemann)) infestation in persimmon by applying a bait spray to adjacent coffee plants (McQuate et al. 2005b). Further research is needed to assess the relative responsiveness of oriental fruit flies to existing protein baits in the litchi orchards relative to baits applied in their alternate host (source) areas.

The MNB pheromone is highly attractive to *C. illepida* and *C. ombrodelta*, and a significant improvement over the OFM pheromone used in the past (Chang 1995). Although trap catch in treated orchards decreased dramatically after the application of Last Call, there was no apparent reduction in oviposition and infestation rate by *Cryptophlebia*. *Cryptophlebia* has many wild hosts and therefore significant mating may have occurred outside the treated orchards. Larger treatment areas may be necessary for Last Call to effectively kill a significant proportion of males thereby reducing reproduction by female moths.

The orchard with the highest levels of both oriental fruit fly and *Cryptophlebia* infestation (Panaewa) had the highest level of fruit defects, with over a quarter of the fruits having some stain. Clearly some control of these pests is needed when populations reach the levels found in that orchard. Further research, though, is needed to better understand the movement (immigration) of both of these pests relative to time of mating in order that baits may be applied where the pests are most responsive and are thereby effective before the pests attempt to oviposit in or on litchi fruits.

Attract-and-kill is a platform technology and could be adapted to many other pest species provided a pheromone or other semiochemical attractant is known, and potentially combination formulations could be developed to provide control for multiple species. Improved attract-and-kill products are clearly needed for oriental fruit fly and *Cryptophlebia*, as well as implementation of larger suppression areas. As improved products are identified, efforts could be made to combine attractants for *Cryptophlebia* and oriental fruit fly into a single formulation to control these two important pests of litchi and longan, *Dimocarpus longan* Lour., in Hawaii.

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