

Mediterranean fruit fly (Dipt., Tephritidae) suppression in persimmon through bait sprays in adjacent coffee plantings*

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Abstract: Oriental persimmon, *Diospyros kaki* L., in Upper Kula on the island of Maui (Hawaii) is attacked by the Mediterranean fruit fly, *Ceratitis capitata* (Wiedemann). Recent suppression trials using mass trapping with a synthetic food-based bait, initiated in alternate host crops before the start of persimmon season, had shown promise as a means of reducing *C. capitata* population levels. However, this did not adequately suppress *C. capitata* population where there were adjacent plantings of coffee, *Coffea arabica* L., a favoured alternate host, which bears fruits before and during the persimmon season. To improve *C. capitata* population suppression, we applied a spinosad-based bait spray to coffee plants, starting before persimmon fruits became susceptible to oviposition by the Mediterranean fruit fly. The bait spray suppressed the *C. capitata* population and led to reduced infestation of both coffee cherries and persimmon fruits. Percentage parasitization of *C. capitata* in coffee cherries by established biological control agents, primarily *Fopius arisanus* (Sonan), was not significantly different in unsprayed vs. sprayed plots even after 11 weekly sprays. These results suggest that mass trapping, combined with spinosad-based bait sprays, are control components that are compatible with biological control and can be combined in an integrated pest management system for *C. capitata*.

Key words: *Ceratitis capitata*, *Fopius arisanus*, integrated pest management, mass trapping, spinosad, suppression

1 Introduction

Oriental persimmons (*Diospyros kaki* L.) have been cultivated in Upper Kula on the island of Maui in Hawaii, since the 1930s. A persistent threat facing persimmon growers is crop loss through infestation by Mediterranean fruit fly, *Ceratitis capitata* (Wiedemann), established in Hawaii in 1910 (BACK and PEMBERTON, 1918). Mediterranean fruit fly populations are maintained throughout the year in Kula through a succession of 'bridge' hosts, with the flies moving from host to host as each crop comes into season. Suppression trials were conducted in Upper Kula in 1988 using augmentative releases of the parasitic wasp *Diachasmimorpha tryoni* (Cameron) (Hym., Braconidae) (WONG et al., 1991), and in 1989 using concurrent parasitoid and sterile Mediterranean fruit fly releases (WONG et al., 1992). Subsequent to these trials, a spinosad-based protein bait spray (GF-120 Fruit Fly Bait; Dow AgroSciences, Indianapolis, IN, USA) and a synthetic food-based attractant (Biolure 3-Component Fruit Fly Bait; Suterra, Wenatchee, WA, USA) have been developed (EPSKY et al., 1999; BROUGHTON and DE LIMA,

2002), both attractive to male and female Mediterranean fruit flies. Spinosad-based protein bait sprays are effective in suppressing Mediterranean fruit fly populations when sprayed on the host plants (PECK and MCQUATE, 2000; BURNS et al., 2001). Biolure has been evaluated extensively for use in monitoring Mediterranean fruit fly populations (EPSKY et al., 1999; KATSOYANNOS et al., 1999; PAPADOPOULOS et al., 2001; BROUGHTON and DE LIMA, 2002) with some research also directed to its potential use in population suppression (COHEN and YUVAL, 2000; ROS et al., 2000; KATSOYANNOS and PAPADOPOULOS, 2004).

In 2000, the US Department of Agriculture (USDA)-Agricultural Research Service (ARS)-US Pacific Basin Agricultural Research Center received funding for an areawide fruit fly integrated pest management programme in Hawaii. As part of this programme, a Mediterranean fruit fly suppression trial was conducted in persimmon orchards in Kula, Maui, based on mass deployment of traps baited with Biolure. These traps were placed in alternate Mediterranean fruit fly host trees which bore fruit before persimmon season started. Alternate hosts included peach [*Prunus persica* (L.)], plum (*Prunus* spp.) and citrus (various *Citrus* spp.). In this trial, good suppression was achieved in persimmon because many of the flies generated from infested alternate hosts which completed fruiting before persimmon season were 'cleaned out' of the orchards before persimmon fruits

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became susceptible to sting damage (G.T. McQUATE, C.D. SYLVA and E.B. JANG, unpublished data). However, on a farm where a favoured alternate host, coffee (*Coffea arabica* L.), bore mature fruits both before and during persimmon season, the mass-trapping approach did not adequately suppress the Mediterranean fruit fly population. Here, we present results of a trial where weekly applications of GF-120 were applied to coffee to reduce Mediterranean fruit fly infestation in an adjacent persimmon orchard. Because Mediterranean fruit fly parasitoids were well established in the coffee fields, we also assessed whether bait sprays adversely affected the parasitoids.

2 Materials and Methods

2.1 Study sites

The trial was conducted on two farms in Upper Kula on the island of Maui, Hawaii (fig. 1), located about 340 m apart. Coffee and persimmon were cultivated on both farms. Because the joint cultivation of coffee and persimmon is uncommon in this area, it was not possible to replicate this study on other farms. It was also not possible to replicate in time, because growers involved in this trial made subsequent use of the techniques tested in the trial and were able to provide continued Mediterranean fruit fly suppression. In

this paper, the trapped site that was not sprayed is referred to as the 'unsprayed site.' The other site is referred to as the 'sprayed site.' The sprayed site had 100 bearing persimmon trees and about 0.8 ha of coffee split between two approximately equal sections, one south (coffee section 1) and the other south-west (coffee section 2) of the persimmon orchard. The grower at the sprayed site covered the persimmon fruits with paper bags to prevent both Mediterranean fruit fly infestation and damage by birds. However, fruits in one section of 13 trees, located adjacent to coffee section 1 (see fig. 1), were left uncovered. These fruits were fully exposed to any ovipositional activity by Mediterranean fruit fly. The unsprayed site had 20 bearing persimmon trees and about 0.3 ha coffee located near the southern end of the persimmon orchard.

2.2 Population monitoring

Multilure traps (Better World Manufacturing, Fresno, CA, USA), baited with Biolure 3-Component Fruit Fly Bait (Suterra) were set out at both farms 2 weeks before the first spray (18 July 2002), and were serviced weekly until 4 weeks after the last bait spray application (10 December 2002). Traps were recharged with fresh Biolure every 8 weeks. Biolure is a synthetic protein bait consisting of separate chemical release packets for ammonium acetate, trimethylamine, and putrescine. At the sprayed site, 18 traps were set out, six in each of two coffee sections and six in the persimmon orchard. Of the six traps in the persimmon orchard, three were spread out in the section where fruits were not bagged. The other three traps were spread out in the orchard with bagged fruits. At the unsprayed site, 12 traps were set out, six in the coffee section and six in the persimmon orchard. All traps were deployed dry and toxicant-free, using a double-sided yellow sticky card (12.7 cm × 8 cm) hung from a 'pinch' at the top of the trap to catch the attracted flies. Trap density was close to the one trap per five fruiting persimmon trees at the sprayed site, the density used in the unpublished mass trapping trials mentioned in the introduction. Trap density was higher at the unsprayed site to provide balanced trap numbers in both coffee and persimmon sections. These trap densities would be expected to have some suppression effect at both the sprayed and unsprayed sites.

2.3 Bait sprays

GF-120 Fruit Fly Bait (Dow AgroSciences) was diluted according to label directions, producing a final toxicant concentration of 0.008% spinosad. The bait was applied weekly at a rate of 4 l/ha to the underside of the coffee leaves at the sprayed site beginning 1 August 2002 using a SP0 Backpack Sprayer (SP Systems, Santa Monica, CA, USA) with a no. 35 disk inserted in the spray line before the spray head. This disk reduced the diameter of the opening through which the bait solution passed which thereby reduced the rate of spray application. Bait sprays were applied as 'spots', with each plant receiving about two 2–3-ml spots each spray. At the time of the study, neither coffee nor persimmon was included on the label for GF-120. An Experimental Use Permit was obtained from the Pesticide Branch of the Hawaii Department of Agriculture to allow sprays on coffee, with the understanding that no coffee would be harvested after the first spray up until the time that no spinosad residue could be detected on coffee cherries. The persimmon trees were not sprayed, permitting the harvesting of the persimmon fruits. The last bait spray (no. 15) was applied on 14 November 2002.

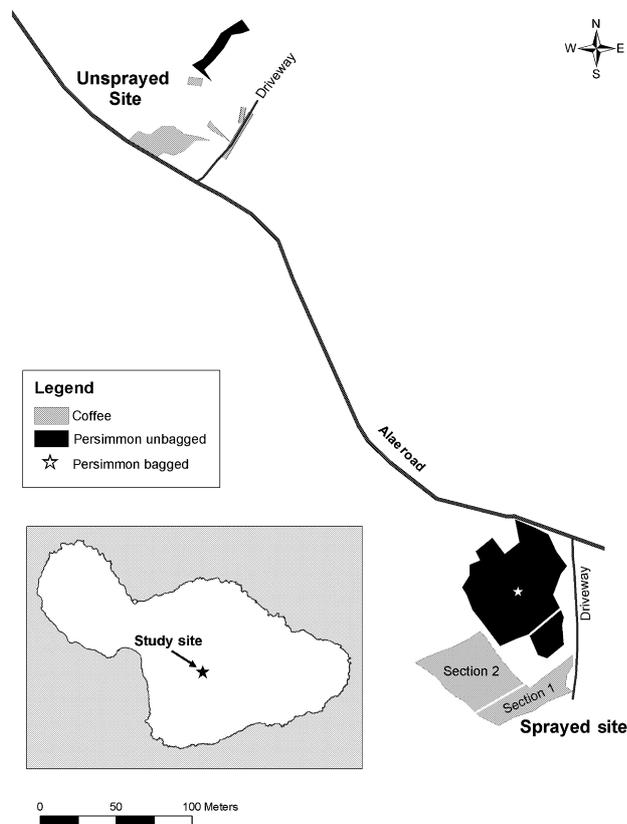


Fig. 1. Site map for study. The section at the sprayed site marked with a star (☆) is the section where persimmon fruits were bagged to prevent bird damage and *Ceratitis capitata* infestation. All other persimmon fruits at the sprayed site and at the unsprayed site were not bagged

2.4 Assessment of fruit infestation

2.4.1 Coffee

Coffee cherries were collected from both sites before spraying (25 July 2002), after four sprays (28 August 2002) and after 11 sprays (24 October 2002). At each collection date, 220 ripe cherries were collected from each of five subdivisions of each of the two coffee sections of the sprayed site. Concurrently, 240 cherries were collected in each of five subdivisions of the coffee section at the unsprayed site. In each subdivision of each site, sampling started at a randomly selected 'start' plant in the row and continued at a randomly selected plant interval along the row, with 10 ripe cherries randomly selected from each plant. Cherries were held in paper bags and chilled after collection to minimize larval emergence from the fruits before fruits were initially processed for assessment of infestation. At the time of processing, 20 cherries were randomly subsampled from cherries collected from each subdivision of the sprayed site, and 40 cherries from each subdivision of the unsprayed site, giving a total of 200 cherries for each site. Coffee cherries were weighed individually and then placed in separate 5.1 cm × 7.6 cm reclosable polybags (Super Zippit, Bagco.com, Kennesaw, GA, USA) which had been perforated to provide aeration and to which 5 ml of sand had been added as a pupation medium. The remaining cherries were held in bulk (200 cherries per subdivision) in screen-topped buckets to which sand had been added. All bulk held coffee cherries and associated sand were checked for tephritid fruit fly pupae and pupating larvae 2 weeks after initial processing. Pupae and pupating larvae were transferred to 8.5 cm (diam) × 4 cm screen-topped plastic cups which held a small amount of sand. Mediterranean fruit flies and parasitoids emerging from the pupae in both individual bags and bulk collections were counted. For the first coffee collection (pre-spray), wherein there was a high level of parasitization, unemerged pupae were not dissected to determine whether they had been parasitized. Unemerged pupae, however, were dissected for the two post-spray coffee collections to give a more complete assessment of parasitization rate.

2.4.2 Persimmon

At the time of the third coffee collection (24 October 2002), 10 mature persimmon fruits were randomly collected from each of 10 trees at the sprayed site and from each of six trees at the unsprayed site. The fruits were weighed, held individually in 1-l screened top plastic containers which held sand at the bottom. The fruits and sand were processed for tephritid fruit flies and parasitoids as described above for coffee cherries. Recovered pupae from which there were no emergences were dissected to give a more complete assessment of parasitization rate.

2.5 Statistical analyses

Although inferential statistics have been considered by some inappropriate for situations where treatment sites are not replicated (HURLBERT, 1984, 2004), others have argued that inferential statistics can still be used, to better inform the reader of the value of the descriptions given, in some cases where it has not been possible to replicate treatment and control sites (OKSANEN, 2001; COTTENIE and DE MEESTER, 2003) provided that caution is exercised in extrapolation of results to other systems. For improved clarity for the reader we have calculated inferential statistics as described below and discuss the potential representativeness of our results in the discussion section. SYSTAT 10 (SPSS, INC., 2000) was used for

statistical analyses. Repeated-measures analysis of variance (ANOVA) was used to assess the significance of differences in trap catch between coffee and persimmon areas on each farm and between coffee areas and between persimmon areas on the sprayed and unsprayed farms. Analysis of variance, with the Bonferroni test for means separation, was used to assess the significance of differences in pre-spray trap catch (to compare pre-spray population levels at the sprayed and unsprayed sites), percentage Mediterranean fruit fly infestation in coffee, percentage parasitization of Mediterranean fruit fly, and Mediterranean fruit fly pupal recovery from infested fruits among the two coffee sections at the sprayed site and the unsprayed site coffee. Trap catch results and pupal recovery counts from infested coffee cherries were square root transformed [$\sqrt{(x + 0.5)}$], and percentage Medfly infestation values and percentage parasitization values were arcsine transformed [$\arcsin(\%/100)$] (SOKAL and ROHLF, 1981), before analysis. Assessment of percentage persimmon infestation, and pupae per kg infested persimmon fruit between the sprayed site and the unsprayed site were made using *t*-tests, with count data square root transformed and percentage data arcsine transformed before analyses. Separate variances for each site were used for the persimmon infestation comparisons. For analysis of percentage infestation of coffee cherries, row infestation totals were used as replicated estimates of percentage infestation. For analysis of percentage infestation of persimmon and pupal recovery per kg persimmon fruit, infestation rate per tree was used as the replicated estimate of infestation.

3 Results

3.1 Mediterranean fruit fly population

Average total (male + female) Mediterranean fruit fly trap catch, through the course of the study, is presented in fig. 2a (coffee areas) and in fig. 2b (persimmon areas).

3.1.1 Mediterranean fruit fly population in coffee

Average total trap catch in coffee was not significantly different among the two coffee sections at the sprayed site and the coffee section at the unsprayed site on either week 1 ($F = 1.236$, d.f. = 2, 15, $P = 0.318$) or week 2 ($F = 0.890$, d.f. = 2, 15, $P = 0.431$), the two trap services completed before the first GF-120 spray, showing that Mediterranean fruit fly populations were similar in both the sprayed site and the unsprayed site at the beginning of the trial. Over the course of the trial, the Mediterranean fruit fly catch was significantly lower in coffee section 2 than in coffee section 1 at the sprayed site ($F = 5.405$, d.f. = 1, 10, $P = 0.042$). Trap catch was also significantly lower at both coffee section 1 ($F = 25.670$, d.f. = 1, 10, $P = 0.000$) and coffee section 2 ($F = 80.416$, d.f. = 1, 10, $P = 0.000$) than at the unsprayed site coffee.

3.1.2 Mediterranean fruit fly population in persimmon

Average total trap catch in persimmon was not significantly different between the sprayed site and the unsprayed site before the first spray application [week 1 ($t = -0.870$, d.f. = 10, $P = 0.405$); week 2

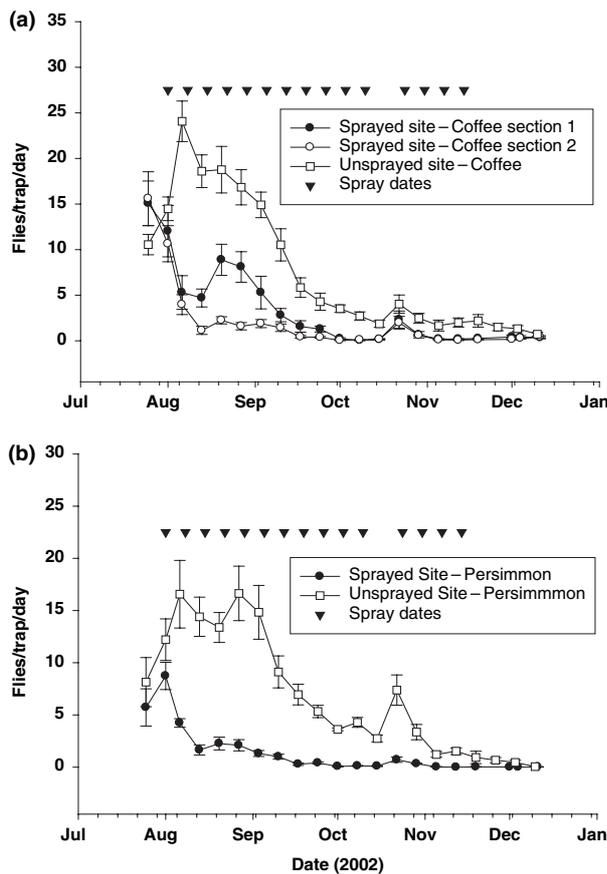


Fig. 2. Average total *Ceratitis capitata* catch at the sprayed site and the unsprayed site throughout the trial in coffee (a) and in persimmon (b), with spray dates indicated at the top of the graph. The first two trap catch points in each figure occurred before the first GF-120 Fruit Fly Bait spray. Overall, trap catch was significantly lower at both coffee sections 1 and 2 at the sprayed site than at the unsprayed site coffee. Overall, trap catch in persimmon was also significantly less at the sprayed site than at the unsprayed site

($t = -1.390$, d.f. = 10, $P = 0.195$]. However, over the course of the trial, Mediterranean fruit fly trap catch was significantly less at the sprayed site than at the unsprayed site ($F = 178.07$, d.f. = 1, 10, $P = 0.000$).

Trap catch averaged $8.11 (\pm 1.45)$ and $6.33 (\pm 1.57)$ flies/trap/day for the 2 weeks before the first spray and $0.64 (\pm 0.22)$ and $0.91 (\pm 0.27)$ flies/trap/day for the remaining weeks of the study for trap sites with bagged fruit and unbagged fruits respectively. The differences in trap catch between sites where fruit had been bagged and where fruit had not been bagged was not significantly different for any time throughout the study. Trap catch comparison through a repeated-measures ANOVA was not possible because of a lack of variability in trap catch in the latter weeks of the trial (too many zero catches).

3.1.3 Comparison of Mediterranean fruit fly populations between persimmon and coffee areas at each site

At the unsprayed site, trap catch in persimmon vs. coffee areas was not significantly different over the

course of the study ($F = 0.441$, d.f. = 1, 10, $P = 0.522$). There was, although, an interesting trend. Trap catch was numerically higher in coffee in weeks 1–8 and 16–21 and numerically higher in persimmon in weeks 9–15, suggesting increased fly movement to persimmon when ripe fruits were present (the persimmon harvest was on week 11). At the sprayed site, trap catch was significantly lower in the persimmon area than in coffee section 1 ($F = 7.718$, d.f. = 1, 10, $P = 0.020$), but was not significantly different between the persimmon area and coffee section 2 ($F = 2.034$, d.f. = 1, 10, $P = 0.184$).

3.2 Fruit infestation

3.2.1 Percentage infestation in coffee

Figure 3 presents the average percentage infestation from the sprayed and unsprayed sites for all three collections of coffee cherries based on the individually bagged fruits. In the coffee cherry collection taken before the first spray there was a significant difference in percentage infestation at the sprayed and unsprayed sites ($F = 12.135$, d.f. = 2, 12, $P < 0.001$). Percentage infestation was significantly higher in both coffee sections of the sprayed site than at the unsprayed site, but not significantly different between the two coffee sections of the sprayed site. In the first coffee cherry collection taken after sprays commenced there was a significant difference in percentage infestation between sprayed and unsprayed sites ($F = 7.787$, d.f. = 2, 12, $P = 0.007$). Percentage infestation was significantly lower in both sections of the sprayed site than at the unsprayed site. Again, there was no significant difference in percentage infestation between the two coffee sections at the sprayed site. At the third coffee cherry collection there was no significant difference in percentage infestation rates among the three sections

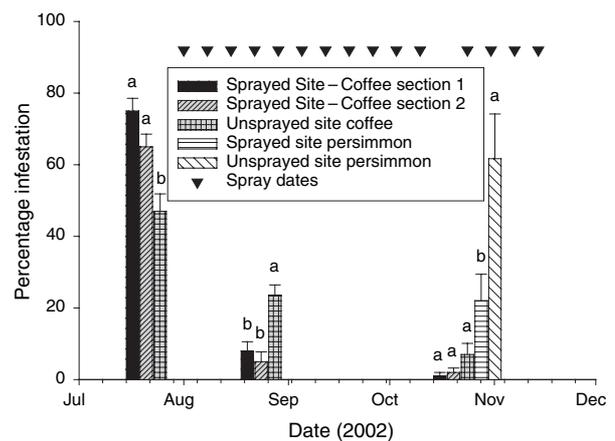


Fig. 3. Average percentage infestation in coffee cherries and persimmon fruits harvested from the sprayed site and the unsprayed site. Spray dates are indicated at the top of the graph. For each collection, columns topped by the same letter are not significantly different at the $\alpha = 0.05$ level. For the third collection percentage infestation was analysed separately for the coffee cherry samples and the persimmon samples

($F = 1.665$, d.f. = 2, 12, $P = 0.230$), although infestation rates were lower in each of the sections at the sprayed site compared with the unsprayed site.

3.2.2 Infestation rate (individuals/kg fruit) in coffee

Figure 4 presents the Mediterranean fruit fly infestation rate (in individuals per kg fruit) based on the bulk fruit collections. In the coffee cherry collection taken before the first spray there was a significant difference in infestation rate at the sprayed and unsprayed sites ($F = 10.307$, d.f. = 2, 12, $P = 0.002$). Infestation rate in coffee section 1 was significantly higher than in the unsprayed site but was not significantly different than in coffee section 2. Infestation rate in coffee section 2 was not significantly different than in the unsprayed site, although was numerically greater. In the first coffee cherry collection taken after sprays were started there was a significant difference in percentage infestation at the sprayed and unsprayed sites ($F = 5.401$, d.f. = 2, 12, $P = 0.021$). Infestation rate was significantly lower in both sections of the sprayed site than at the unsprayed site while there was no significant difference in infestation rate between the two coffee sections at the sprayed site. At the third coffee cherry collection there was no significant difference in percentage infestation rates among the three sections ($F = 1.882$, d.f. = 2, 12, $P = 0.195$), although infestation rates were lower in each of the sections at the sprayed site compared with the unsprayed site.

3.2.3 Persimmon infestation

Figures 3 and 4 present the average percentage infestation and pupae per kg of infested fruit, respectively, of persimmon fruits from the sprayed and unsprayed

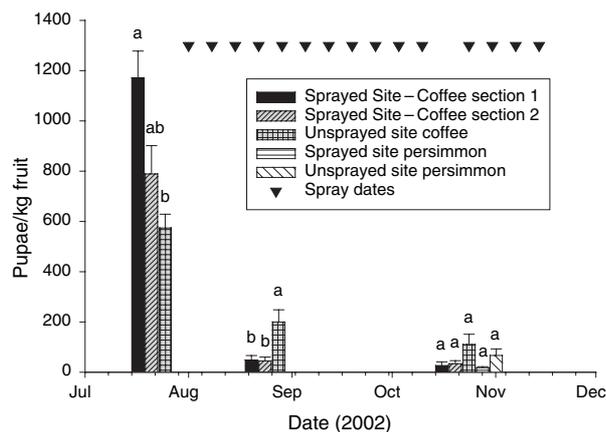


Fig. 4. Average number of *Ceratitidis capitata* pupae recovered per kilogram of coffee cherries and average number of *C. capitata* pupae per kg of infested persimmon fruits harvested from the sprayed site and the unsprayed site over the course of the study. Spray dates are indicated at the top of the graph. For each collection, columns topped by the same letter are not significantly different at the $\alpha = 0.05$ level. For the third collection percentage infestation was analysed separately for the coffee cherry samples and the persimmon samples

sites. There was a significant difference in percentage infestation between the sprayed site (22.0%) and the unsprayed site (61.7%) ($t = 2.809$, d.f. = 9.3, $P = 0.020$). There was also a significant difference in pupal recovery per kg fruit between the sprayed site (12.5) and the unsprayed site (66.5) ($t = 2.870$, d.f. = 7.0, $P = 0.024$), but, when only infested fruits are considered, the difference in pupal recovery per infested fruit (17.8 vs. 66.5 respectively) was not significant ($t = 2.276$, d.f. = 6.4, $P = 0.060$). All tephritid fruit flies recovered from the sprayed site were Mediterranean fruit fly, but 3.3% of the fruits from the unsprayed site were infested by both Mediterranean fruit fly and oriental fruit fly [*Bactrocera dorsalis* (Hendel)].

3.3 Mediterranean fruit fly parasitization in coffee

3.3.1 Parasitoid species recovered

Two species of Mediterranean fruit fly parasitoid were recovered from coffee cherries collected both from the sprayed site and from the unsprayed site. *Fopius arisanus* (Sonan) was the predominant species, while *Diachasmimorpha tryoni* (Cameron) was also present.

3.3.2 Percentage parasitization from individually bagged cherries

Both parasitoid species were recovered from both sites in the first coffee cherry collection, but only *F. arisanus* was recovered in the second and third collections. In the first collection, 93.8% of parasites recovered were *F. arisanus*. Percentage parasitization by *F. arisanus* was not significantly different among coffee sections for the first ($F = 2.264$, d.f. = 2, 12, $P = 0.147$), second ($F = 1.801$, d.f. = 2, 9, $P = 0.220$) or third ($t = 0.592$, d.f. = 2, 5, $P = 0.602$) coffee cherry collections.

3.3.3 Percentage parasitization rate from bulk held cherries

Parasitization rate for each collection is presented in table 1. Both parasitoid species were recovered in all three collections at both sites. Averaged over all three collections, *F. arisanus* accounted for 92.9% of all recovered parasitoids. Differences in percentage parasitization were not significant for the first ($F = 1.527$, d.f. = 2, 12, $P = 0.257$) second ($F = 1.560$, d.f. = 2, 12, $P = 0.250$) or third ($F = 0.765$, d.f. = 2, 9, $P = 0.493$) coffee cherry collection.

3.3.4 Parasitoids recovered per kg coffee cherries (bulk held)

Average total parasites recovered per kg of coffee cherry collected in each collection at each site is presented in table 1. At the first collection, there was a significant difference in parasitoid levels ($F = 10.785$, d.f. = 2, 12, $P = 0.002$), with coffee section 1 having more parasites than either coffee section 2 or the unsprayed site coffee section. There was no significant

Table 1. Recovery of *Ceratitis capitata* and two parasitoid species from three bulk coffee cherry collections at both the sprayed and unsprayed sites

Collection Date	No.	Treatment	Coffee cherries		Pupae recovered		<i>C. capitata</i>		<i>F. arisanus</i>		<i>D. tryoni</i>		Total no. of parasitoids	Avg. parasitoids per kg fruit	Avg. % parasitization
			No.	Weight (g)	No.	UE (Par)	M	F	M	F	M	F			
7/25	1	SpraySect1	1000	1064.6	1253	274	224	258	215	254	12	16	497	462.7 (84.8) a	38.9 (4.4) a
7/25	1	SpraySect2	1000	1112.8	880	146	221	251	105	138	8	11	262	234.4 (30.7) b	30.3 (2.7) a
7/25	1	Unsprayed	1000	1350.6	770	162	157	220	72	133	14	12	231	168.9 (19.6) b	30.6 (4.4) a
8/28	2	SpraySect1	1000	1109.8	54	28 (17)	5	6	6	8	0	1	32	28.8 (9.5) a	67.2 (13.4) a
8/28	2	SpraySect2	1000	1188.7	54	28 (12)	5	4	10	7	0	0	29	24.1 (7.7) a	57.1 (11.7) a
8/28	2	Unsprayed	1000	1363.2	278	166 (62)	17	25	29	39	2	0	132	94.9 (25.1) a	38.5 (9.9) a
10/24	3	SpraySect1	1000	1260.4	34	15 (9)	8	5	1	4	0	1	15	11.5 (10.6) a	22.2 (15.0) a
10/24	3	SpraySect2	1000	1322.9	43	9 (5)	12	19	0	3	0	0	8	6.9 (5.0) a	16.0 (9.3) a
10/24	3	Unsprayed	879	740.8	103	21 (17)	36	33	10	2	2	0	31	32.9 (14.6) a	32.1 (8.4) a

Calculations on parasitoid levels for coffee cherry collection numbers 2 and 3 include unemerged pupae (UE) found to be parasitized, which are indicated in parentheses, and are based on row averages. Unemerged pupae from the first coffee cherry collection were not opened to check for parasitization. For a given collection number, 'parasitoids per kg fruit' and '% parasitization' (\pm SEM) followed by the same letter are not significantly different at the $\alpha = 0.05$ level.

difference in parasitoid levels among coffee sections at either the second or third coffee cherry collection, although parasitoid numbers were numerically lower in both of the sprayed site coffee sections for both collections.

3.4 Mediterranean fruit fly parasitization in persimmon

No parasitized Mediterranean fruit fly pupae were recovered from persimmon fruits at the sprayed site. However, 6.7% of Mediterranean fruit fly pupae recovered from persimmon at the unsprayed site were parasitized by *F. arisanus*.

4 Discussion

Effects of the bait spray on Mediterranean fruit fly population in coffee at the sprayed site closely parallel those found in a previous spinosad-based bait spray trial in coffee (PECK and McQUATE, 2000). In that study, there was also significant drop in trap catch after one spray and infestation rate in the coffee cherries had dropped from about 63 individuals per kg fruit to near zero after four weekly sprays. Infestation rate in the present study, though, had started out much higher. The parallel results are to be expected because a protein bait attractive to *C. capitata* (Mazoferm E802; Corn Products, Argo, IL, USA) had been used with the spinosad in the previous study and the GF-120 used in this study had been formulated in part based on effectiveness against *C. capitata*. The timing and magnitude of the major short-term effects found in this study, occurring at a timing previously observed for effects of a spinosad-based bait spray, provide strong corroboration that the differences in results of our unreplicated treatment and unreplicated control are tied to the bait spray application and do not result from other unspecified differences between the sites. In such situations OKSANEN (2004) argues that the observed differences can be interpreted as effects of the treatment, but that the results don't represent statistically demonstrated treatment effects.

The results of the present trial, guided by experience with previous trials, showed that the bait sprays clearly suppressed the Mediterranean fruit fly population at the sprayed site. The suppression was apparent from the first trap catch and first cherry collection after spraying started. Population suppression was seen in both coffee areas and the persimmon area of the sprayed site, even though no sprays were applied to the persimmon area. The use of perimeter control strategies for Mediterranean fruit fly has previously received attention. COHEN and YUVAL (2000) found that mass trapping using traps baited with three component synthetic protein bait, placed in the peripheral rows of plum, pear, and persimmon orchards, helped protect fruits from Mediterranean fruit fly infestation. In a mixed host environment where the flies use the various hosts 'as stepping stones, moving from one to another as fruit mature throughout the season' (COHEN and YUVAL, 2000) movement from host to host needs to be prevented. Suppression within adjacent cropping areas

which fruit immediately before or during the fruiting of the crop to be protected help prevent this movement. At our unsprayed site, mass trapping in both the persimmon orchard and the adjacent coffee field did not prevent population build-up in the persimmon orchard at the unsprayed site. This is consistent with our earlier experience that shifting traps from adjacent fruiting coffee to the persimmon orchard, as the persimmon fruit matured and became more susceptible to Mediterranean fruit fly oviposition, did not adequately suppress population levels (G.T. MCQUATE, C.D. SYLVA and E.B. JANG, unpublished data). In the present study, spraying the adjacent favoured alternate host, in addition to trapping, led to reduced fly levels and reduced infestation rates in both coffee cherries and persimmon at the sprayed site. However, further research is needed to assess the cost effectiveness of this two-technique (bait spray and mass trapping) suppression system, especially considering that COHEN and YUVAL (2000) indicated that cost effectiveness could potentially limit the commercial use of their perimeter mass trapping system.

As a relatively new product, effectiveness of GF-120 has not been well documented for many fruit fly species. PROKOPY et al. (2003) reported that GF-120 effectively suppressed protein-deprived female melon flies [*Bactrocera cucurbitae* (Coquillett)] but was less effective in suppressing protein-fed females. BARRY et al. (2003) found that, although Mediterranean fruit fly attraction appeared to be limited to several cm from the bait, all flies that came in direct contact with the bait died within 48 h. In the field trial reported here, the bait was applied as spots rather than as a cover spray, so distances between spots would be considerably more than 'several cm.' Good suppression was observed, but a closer distribution of smaller spots could have further improved suppression. Further field trials are needed to assess application methodologies, the duration of attractiveness, and the duration of effectiveness of GF-120 in suppression of Mediterranean fruit fly populations.

The bait spray used in this study, GF-120, is a commercially available product which is labelled for fruit fly control on many crops. Although, at the time of this study, neither coffee nor persimmon was included on the product label, there is anticipation that an 'all-crops' label is forthcoming which would make this spray available for commercial use on coffee and persimmon. Although this paper has shown that Mediterranean fruit fly can be suppressed in persimmon orchards through bait sprays in adjoining coffee plantings, an 'all crops' label could improve levels of suppression by additionally permitting direct spraying on foliage in the persimmon orchard as flies become more attracted to ripening persimmons.

In addition to effectively suppressing Mediterranean fruit fly populations and reducing crop damage, suppression techniques must have minimal adverse effects on non-target species and the environment. MICHAUD (2003), in laboratory studies, found that GF-120 is highly attractive and lethal to parasitoid wasps [*Aphytis melinus* DeBach (Hym., Aphelinidae)

and *Lysiphlebus testaceipes* Cresson (Hym., Aphididae)]. In further laboratory studies, EDWARDS et al. (2003) found that Success 0.02 CBTM (GF-120) (the name under which GF-120 is marketed in Guatemala and most Central American countries) is toxic to honey bees, *Apis mellifera* L., but called for further studies to evaluate its effects in the field on foraging honey bees and brood health during a season long *C. capitata* control programme to better assess possible honeybee impacts. In the present study, however, we found that parasitoids established in the field against Mediterranean fruit fly (primarily *F. arisanus*) maintained their parasitization rate over the course of the suppression activities, although their population levels decreased numerically. VARGAS et al. (2001) found that *F. arisanus* population levels declined rapidly as the *C. capitata* population declined, but rebounded with the cessation of spinosad-based bait spray treatments (GF-120 was not used in that trial). In more recent tests it was found that *F. arisanus* fed very little on protein baits (VARGAS et al., 2002) and that contact toxicity occurred only at 'extremely high concentrations that are unlikely to occur after application of bait sprays' (STARK et al., 2004). These results suggest that GF-120 sprays are compatible with established biological control agents. However, further studies are needed to more carefully assess the possible effects of bait sprays on established parasitoid species, as well as on other non-target species.

In conclusion, this trial has shown that GF-120 sprays, in conjunction with synthetic food bait - based mass trapping, can be a valuable tool in an integrated pest management programme for suppressing Mediterranean fruit fly populations in coffee. This suppression can reduce population levels and infestation rates in adjacent persimmon orchards. Furthermore, these combined techniques seem to integrate well with biological control by established parasitoid species.

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