

Captures of Wild *Ceratitis capitata*, *Bactrocera dorsalis*, and *Bactrocera cucurbitae* (Diptera: Tephritidae) in Traps with Improved Multilure TMR Dispensers Weathered in California

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Received 22 June 2015; Accepted 26 October 2015

Abstract

During 2012–2013, solid Mallet TMR (trimedlure [TML], methyl eugenol [ME], raspberry ketone [RK]) wafers impregnated with DDVP (2, 2-dichlorovinyl dimethyl phosphite) insecticide were weathered during summer (8 wk) and winter (12 wk) in five California citrus-growing counties (Kern, Ventura, Orange, Tulare, and Riverside). In addition, TMR wafers without DDVP and with a Hercon Vaportape II insecticidal strip were compared with TMR dispensers with DDVP at Exeter and Riverside. Weathered treatments were shipped every week (overnight delivery) to Hawaii and frozen for a later bioassay in a 1,335-ha coffee plantation near Numila, Kauai Island, HI, where Mediterranean fruit fly, *Ceratitis capitata* (Wiedemann), oriental fruit fly, *Bactrocera dorsalis* Hendel, and melon fly, *Bactrocera cucurbitae* Coquillett, were all present. We compared trap captures of the three species, *C. capitata*, *B. dorsalis*, and *B. cucurbitae*, for the five different weathering locations. Captures of *C. capitata*, *B. dorsalis*, and *B. cucurbitae* with Mallet TMR dispensers (with DDVP) were not significantly different for the five locations. Captures with the Mallet TMR dispenser without DDVP and Vaportape were similar to those for Mallet TMR with DDVP, although there were some slight location differences. In conclusion, based on these results, the Mallet TMR dispenser could potentially be used in California habitats where large numbers of detection traps are currently deployed. Use of Vaportape with dispensers would not require them to be registered with US Environmental Protection Agency (EPA). Dispensers for use as Male Annihilation Technique (MAT) devices will be tested further in Hawaii.

Key words: Tephritidae, fruit fly, detection, survey, eradication program

Fruit flies (Diptera: Tephritidae) are a significant economic and agricultural concern worldwide because of the wide range of fruits, nuts, and vegetables infested (White and Elson Harris 1992). The genera *Ceratitis*, *Anastrepha*, and *Bactrocera* pose the greatest risk to agriculture in the United States (United States Department of Agriculture–Animal and Plant Health Inspection Service [USDA-APHIS] 2011). The potential of spreading these pests has increased with increased fruit and vegetable production worldwide,

globalization of trade, and movement of people (USDA-APHIS 2006). Fruit flies create adverse economic and environmental consequences associated with detection and eradication programs, imposed quarantines, market loss due to trade restrictions, and reduced production and diversification of agriculture. To mitigate the possibility of establishment in uninfested areas, research and development of improved detection and male annihilation systems is crucial to exclusion and suppression programs worldwide.

There are >160,000 federal and state fruit fly detection traps deployed in southern and western U.S. States and Puerto Rico. In California alone, >63,000 traps are deployed and maintained just for exotic fruit flies detection (California Department of Food and Agriculture [CDFA] 2013). Fruit fly detection and eradication requires deployment of large numbers of traps individually baited with the highly attractive male-specific lures trimedlure (TML; t Butyl-4 (or5)-chloro-2-methyl cyclohexane carboxylate), cue-lure (CL; 4-(p-acetoxypheyl)-2-butanone), and methyl eugenol (ME; 4-allyl-1,2-dimethoxybenzene-carboxylate), to combat such pests as the Mediterranean fruit fly, *Ceratitis capitata* (Wiedemann), melon fly, *Bactrocera cucurbitae* Coquillett, and oriental fruit fly, *Bactrocera dorsalis* Hendel, respectively (Vargas et al. 2010). In conjunction with these liquid attractants, current “killing” methods include broad-spectrum liquid insecticides, such as naled (dimethyl 1, 2-dibromo-2, 2-dichloroethyl phosphate), or malathion (0, 0-dimethyl phosphorodithioate of diethyl mercaptosuccinate), which may pose environmental and worker safety challenges (Vargas et al. 2009). Many of these organophosphate insecticides are being banned in the European Union; however, until reduced-risk alternatives for fruit fly control are approved, products that contain dichlorvos are still registered, labeled, and used in the United States. Approximately 90% of the *Bactrocera* species respond to either ME or CL, and three species of *Ceratitis* are known to respond to TML (Vargas et al. 2012). As a result, replacing traditional liquid formulations of lures (particularly for ME- and CL-responding fruit flies; the TML plug is already used in U.S. programs) and insecticides with safer alternatives without compromising performance levels has been a primary research goal (Vargas et al. 2008).

The objective of this study was to evaluate Mallet TMR (trimedlure [TML], methyl eugenol [ME], raspberry ketone [RK]) wafers impregnated with DDVP (2, 2-dichlorovinyl dimethyl phosphate) insecticide dispensers as convenient, effective, and safer means to use male lures and insecticides for improved detection and potentially improved male annihilation of invasive fruit flies (Vargas et al. 2013). The alternative of impregnating DDVP into a dispenser (like Mallet TMR) or the use of an insecticidal strip (Hercon Vaportape II, Hercon Environmental, Emigsville, PA) is still a step forward when compared with liquid formulations of the same insecticide. Furthermore, registration of Mallet TMR wafer with DDVP may not be economically feasible. Therefore, we tested the insecticidal strips (which are already registered) to determine their potential use as a substitute for wafers impregnated with DDVP.

The current study evaluates the performance and longevity of novel Mallet TMR wafers weathered inside standard Jackson traps under varying climate conditions in five citrus-growing regions of California by analyzing captures of wild fruit flies in bioassays conducted in Hawaii. These areas are representative of major habitats in California where one of the largest fruit fly detection trapping grids in the United States is maintained and where fruit fly detections, eradication programs, and quarantines have occurred. Further comparisons of this improved trapping system include weathered treatments of Mallet TMR wafers impregnated with DDVP versus Mallet TMR wafers without DDVP and combined with an insecticidal strip.

Materials and Methods

California Weathering of Mallet TMR

Mallet TMR wafers were deployed and weathered in five California locations: Exeter (Tulare Co.), Riverside (Riverside Co.), Bakersfield

(Kern Co.), Irvine (Orange Co.), and Ventura (Ventura Co.; GPS locations are listed in Table 1). Sites in California were counties of previous fruit fly detections or areas susceptible to fruit fly infestation. All weathering sites in California were in *Citrus* spp. orchards. Summer weathering of wafer treatments (8 wk) was conducted from 24 July–18 September 2012, and winter weathering (12 wk) was conducted from 8 January–2 April 2013.

Two treatments were weathered: 1) Mallet TMR 6M (10.4% TML, 27.1% ME, 10.4% RK, 3.6% DDVP, one lure contained ~10.6 g AI; 5.0 by 8.0 cm²; Farma Tech International, North Bend, WA) and 2) Mallet TMR 6M without DDVP (10.4% TML, 27.1% ME, 10.4% RK) and combined with insecticidal strip Hercon Vaportape II (2, 2-dichlorovinyl dimethyl phosphate, 10% by weight, 2.5 by 10 cm²). Cue-lure has never been isolated as a natural product but quickly hydrolyzes to form raspberry ketone (RK; 4-(p-hydroxyphenyl)-2-butanone; Vargas et al. 2010). RK is thought to be the attractive molecule and is more persistent because it volatilizes at a lower rate than CL (Metcalf and Metcalf 1992). Mallet TMR treatments were deployed simultaneously inside a standard Jackson trap (Sentry Biological Inc., Billings, MT) with a sticky insert at each weathering site and trial. For each treatment, four trees within a citrus orchard at each location were selected based on orientation in one of the four cardinal directions (North, South, East, and West; four replicates). Three weathering lines were strung under the canopy of each tree. For each week of the trial, one sample from each of the three weathering lines per tree (one for chemical analysis, one for bioassay, and one back up) was removed. In total, 12 wafers per week from each location were sent overnight delivery, four wafers going to North Bend, WA, for chemical analysis (R. I. V. unpublished data), and eight wafers to Hawaii. Samples were individually tightly wrapped in tinfoil, labeled with the location, cardinal direction, treatment, and date; then double bagged, placed in a plastic container and boxed. Once received in Hawaii, samples were placed in a freezer held at 0°C until deployed in the field trials. Only Exeter and Riverside locations included weathered Mallet TMR without DDVP combined with an insecticidal strip. At each California location, temperature and relative humidity (%RH) were recorded at 1-h intervals during weathering of treatments using a data logger (HOBO Pro Series, Onset Computer Corporation, Bourne, MA).

Hawaii Bioassay of Mallet TMR

Evaluations of Mallet TMR dispensers were conducted by the Agricultural Research Service, U.S. Department of Agriculture, Daniel K. Inoué Pacific Basin Agricultural Research Center, Hilo, HI. Bioassays were conducted near Numila, Kauai Island, HI, at a large (ca. 1,400 ha) commercial coffee [*Coffea arabica* L. cv. Arabica (Rubiaceae)] plantation (21° 54'36" N, 159° 32' 54" W, at an average elevation of 125 m) where *C. capitata*, *B. dorsalis*, and *B. cucurbitae* occurred together. Field attraction experiments were conducted 3–10 December 2012 for summer samples and 18–22 November 2013 for winter samples using a randomized complete block design (four blocks) to quantify the relative attractiveness of each weathered Mallet TMR treatment inside Jackson traps to wild male *B. dorsalis*, *B. cucurbitae*, and *C. capitata*. A sticky surface is still needed in order to allow fruit fly counts to be made for this evaluation, particularly for the larger *Bactrocera* species that need a “knock down” insecticide. Otherwise, these fruit flies could potentially escape the sticky insert.

Four individuals were required to deploy and service the trap sets. Traps were placed 20 m apart, and sticky inserts from Jackson traps

were removed for fruit fly counts after 1 h and replaced with a new one. Due to differences in species population, responses for *B. dorsalis* and *C. capitata* were evaluated at 1 h after deployment, and *B. cucurbitae* were assessed with cumulative totals at 24 h. Fresh wafers from the same manufactured batch were deployed as controls.

Statistical Analysis

By comparing mean number of flies captured inside traps from different age dispensers and weathering locations, the relative attraction of the dispensers was determined for the five locations. *C. capitata* and *B. dorsalis* captures were transformed by logs and analyzed using PROC MIXED. *B. cucurbitae* captures, because of the small numbers, were fit to a Poisson or negative binomial distribution using PROC GLIMMIX (SAS Institute 2013). For the randomized complete block, split plot in time mixed model, the fixed effects were location, treatment, week, and the interactions. The random effect was trap within location and the Vaportape treatment. Back transformed geometric means (\pm SEM) based on the upper limit are presented in all tables.

Results

For the summer weathering trials (24 July–18 September 2012), *C. capitata* captures for the dispensers from the five locations

(Bakersfield, Ventura, Irvine, Exeter, and Riverside) were not significantly different ($F=0.65$; $df=4, 15$; $P=0.6369$); however, captures by week were significantly different ($F=6.51$; $df=8, 120$; $P<0.0001$; Table 2). Likewise, *B. dorsalis* captures for the dispensers from the five locations were not significantly different ($F=0.12$; $df=4, 15$; $P=0.9720$); however, captures by week were significantly different ($F=2.01$; $df=8, 120$; $P=0.0505$). Finally, for *B. cucurbitae* captures, the effect of week ($F=3.03$; $df=8, 120.5$; $P=0.0038$) and the site \times week interaction ($F=2.02$; $df=32, 120.5$; $P=0.0034$) were significantly different. Estimates for the captures by site and by week are summarized in Table 3.

For the winter (8 January–2 April 2013) weathering trials, *C. capitata* captures for the dispensers from the five locations (Bakersfield, Ventura, Irvine, Exeter, and Riverside) were not significantly different ($F=0.06$; $df=4, 15$; $P=0.9927$); however, captures by week were significantly different ($F=28.01$; $df=12, 180$; $P<0.0001$; Table 4). *B. dorsalis* captures were not significantly different by location ($F=0.21$; $df=4, 15$; $P=0.9284$) or week ($F=1.76$; $df=12, 180$; $P=0.0575$). *B. cucurbitae* captures were not significantly different by location ($F=2.52$; $df=4, 18.01$; $P=0.0775$) or week ($F=0.87$; $df=12, 181.3$; $P=0.0913$; Table 5).

In studies of the two insecticide delivery systems at Exeter and Riverside during summer, for *C. capitata*, significant differences were found for location ($F=19.98$; $df=1, 12$; $P=0.0008$), week ($F=7.81$; $df=8, 96$; $P<0.0001$), and the location \times treatment

Table 1. Mean temperature and RH% (\pm SEM) during summer (24 July–18 September 2012) and winter (8 January–2 April 2013) weathering of Mallet TMR treatments at five California citrus-growing locations

Location	GPS location	Summer		Winter	
		Temp. °C	RH%	Temp. °C	RH%
Exeter	36° 12'5.54" N, 119° 3'31.68" W	27.57 \pm 0.12	44.57 \pm 0.33	11.18 \pm 0.14	74.78 \pm 0.46
Riverside	33° 58'7.93" N, 117° 20'14.53" W	25.69 \pm 0.12	55.69 \pm 0.41	12.56 \pm 0.14	62.94 \pm 0.62
Bakersfield	35° 19'53.38" N, 118° 53'52.56" W	27.98 \pm 0.12	39.37 \pm 0.30	10.92 \pm 0.15	74.13 \pm 0.48
Irvine	33° 41'14.17" N, 117° 43'13.97" W	23.44 \pm 0.10	67.29 \pm 0.40	13.21 \pm 0.13	66.31 \pm 0.60
Ventura	34° 19'33.14" N, 119° 6'27.44" W	20.14 \pm 0.14	74.99 \pm 0.47	12.21 \pm 0.13	67.56 \pm 0.61

Table 2. Male *C. capitata* and *B. dorsalis* captures (mean \pm SEM flies per trap per five locations) in Jackson traps (1 h) with Mallet TMR dispensers weathered in five California locations (24 July–18 September 2012) and bioassayed at Kauai Coffee Plantation, Numila, HI (3–10 December 2012)

Species	Fresh	1 wk	2 wk	3 wk	4 wk	5 wk	6 wk	7 wk	8 wk
<i>C. capitata</i>	56.1 \pm 8.7	70.4 \pm 10.9	55.6 \pm 8.6	47.3 \pm 7.4	45.3 \pm 7.1	38.6 \pm 6.1	35.8 \pm 5.6	32.8 \pm 5.2	21.8 \pm 3.4
<i>B. dorsalis</i>	5.7 \pm 1.6	4.5 \pm 1.3	5.0 \pm 1.4	4.1 \pm 1.1	4.7 \pm 1.3	3.5 \pm 1.1	3.6 \pm 1.1	3.8 \pm 1.1	2.1 \pm 0.7

For *C. capitata* captures, there were significant differences for week ($F=6.51$; $df=8, 120$; $P<0.0001$); there were no significant differences for location ($F=0.65$; $df=4, 15$; $P=0.6369$) and location \times week interaction ($F=0.69$; $df=32, 120$; $P=0.8898$). For *B. dorsalis* captures, there were significant differences for week ($F=2.01$; $df=8, 120$; $P=0.0505$); there were no significant differences for location ($F=0.12$; $df=4, 15$; $P=0.9720$) and location \times week interaction ($F=0.82$; $df=32, 120$; $P=0.7373$), PROC MIXED (SAS Institute 2013).

Table 3. Male *B. cucurbitae* captures (mean \pm SEM flies per trap) in Jackson traps (24 h) with Mallet TMR dispensers weathered in five California locations (24 July–18 September 2012) and bioassayed at Kauai Coffee Plantation, Numila, HI (3–10 December 2012)

Location	Fresh	1 wk	2 wk	3 wk	4 wk	5 wk	6 wk	7 wk	8 wk
Bakersfield	0.71 \pm 0.63	0.71 \pm 0.63	0.23 \pm 0.48	0.47 \pm 0.55	0.23 \pm 0.48	0.23 \pm 0.48	0.23 \pm 0.48	0.47 \pm 0.55	-0.02 \pm 0.39
Ventura	2.48 \pm 1.12	0.56 \pm 0.56	0.56 \pm 0.58	0.56 \pm 0.56	0.78 \pm 0.62	0.78 \pm 0.62	1.63 \pm 0.87	0.78 \pm 0.62	0.78 \pm 0.62
Irvine	1.22 \pm 0.78	0.98 \pm 0.71	0.24 \pm 0.48	1.22 \pm 0.78	0.73 \pm 0.64	-0.01 \pm 0.40	0.73 \pm 0.64	-0.01 \pm 0.40	-0.01 \pm 0.40
Exeter	2.09 \pm 1.02	-0.03 \pm 0.38	0.68 \pm 0.61	0.44 \pm 0.54	-0.03 \pm 0.38	0.73 \pm 0.64	-0.03 \pm 0.38	0.91 \pm 0.68	1.15 \pm 0.75
Riverside	0.90 \pm 0.68	0.67 \pm 0.61	0.20 \pm 0.46	0.90 \pm 0.68	1.14 \pm 0.75	1.14 \pm 0.75	0.67 \pm 0.61	4.65 \pm 0.5	0.20 \pm 0.46

There were significant differences for week ($F=3.03$; $df=8, 120.5$; $P=0.0038$) and the location \times week interaction ($F=2.02$; $df=32, 120.5$; $P=0.0034$); there were no significant differences for location ($F=0.77$; $df=4, 16.72$; $P=0.5601$), PROC GLIMMIX (SAS Institute 2013).

Table 4. Male *C. capitata* and *B. dorsalis* captures (mean \pm SEM flies per trap per five locations) in Jackson traps (1 h) with Mallet TMR dispensers weathered in five California locations (8 January–2 April 2013) and bioassayed at Kauai Coffee Plantation, Numila, HI (18–22 November 2013)

Species	Fresh	1 wk	2 wk	3 wk	4 wk	5 wk	6 wk	7 wk	8 wk	9 wk	10 wk	11 wk	12 wk
<i>C. capitata</i>	6.3 \pm 1.5	70.4 \pm 14.9	55.6 \pm 11.8	47.3 \pm 10.2	43.5 \pm 10.1	45.3 \pm 9.6	38.6 \pm 8.3	35.8 \pm 7.7	32.8 \pm 7.0	21.6 \pm 4.7	6.3 \pm 1.5	8.1 \pm 1.9	6.1 \pm 1.5
<i>B. dorsalis</i>	15.7 \pm 4.9	8.0 \pm 2.7	8.1 \pm 2.7	9.9 \pm 3.2	9.4 \pm 3.1	7.3 \pm 2.4	7.2 \pm 2.4	6.3 \pm 2.2	8.5 \pm 2.8	9.5 \pm 3.1	8.2 \pm 2.7	8.1 \pm 2.7	12.3 \pm 3.9

For *C. capitata* captures, there were significant differences for week ($F=28.01$; $df=12, 180$; $P<0.0001$); there were no significant differences for location ($F=0.06$; $df=4, 15$; $P=0.9927$) and the location \times week interaction ($F=0.53$; $df=48, 180$; $P=0.9949$). For *B. dorsalis* captures, there were no significant differences for location ($F=0.21$; $df=4, 15$; $P=0.9284$), week ($F=28.01$; $df=12, 180$; $P=0.0575$), and for the location \times week interaction ($F=0.96$; $df=48, 180$; $P=0.5528$), PROC MIXED (SAS Institute 2013).

Table 5. Male *B. cucurbitae* captures (mean \pm SEM flies per trap) in Jackson traps (24 h) with Mallet TMR dispensers weathered in five California locations (8 January–2 April 2013) and bioassayed at Kauai Coffee Plantation, Numila, HI (18–22 November 2013)

Location	Fresh	1 wk	2 wk	3 wk	4 wk	5 wk	6 wk	7 wk	8 wk	9 wk	10 wk	11 wk	12 wk
Bakersfield	0.2 \pm 0.6	0.5 \pm 0.7	0.5 \pm 0.7	1.2 \pm 0.9	0.5 \pm 0.7	3.0 \pm 1.2	1.0 \pm 0.8	1.5 \pm 0.9	1.0 \pm 0.8	0.2 \pm 0.6	0.2 \pm 0.6	1.2 \pm 0.9	0.2 \pm 0.6
Ventura	1.5 \pm 0.9	0.7 \pm 0.7	0.5 \pm 0.7	0.2 \pm 0.6	2.7 \pm 1.2	0.2 \pm 0.6	0.2 \pm 0.6	1.0 \pm 0.8	0.5 \pm 0.7	0.5 \pm 0.7	0.5 \pm 0.7	0.5 \pm 0.7	1.0 \pm 0.8
Irvine	1.4 \pm 0.9	3.0 \pm 1.3	3.2 \pm 1.3	2.8 \pm 1.2	1.6 \pm 0.9	0.9 \pm 0.8	0.4 \pm 0.6	2.0 \pm 1.0	2.5 \pm 1.2	1.4 \pm 0.9	2.3 \pm 1.7	1.1 \pm 0.8	2.3 \pm 1.3
Exeter	3.1 \pm 1.3	0.5 \pm 0.7	0.7 \pm 0.7	0.5 \pm 0.7	0.7 \pm 0.7	0.5 \pm 0.7	0.5 \pm 0.7	0.5 \pm 0.7	0.7 \pm 0.7	0.5 \pm 0.7	0.2 \pm 0.6	0.5 \pm 0.7	0.5 \pm 0.7
Riverside	1.0 \pm 0.8	0.3 \pm 0.6	1.2 \pm 0.9	0.3 \pm 0.6	0.3 \pm 0.6	0.7 \pm 0.7	0.7 \pm 0.7	1.7 \pm 1.0	0.5 \pm 0.7	0.5 \pm 0.7	0.5 \pm 0.7	0.0 \pm 0.5	0.3 \pm 0.6

There were no significant differences for location ($F=2.52$; $df=4, 18.01$; $P=0.0775$), week ($F=0.87$; $df=12, 181.3$; $P=0.5746$), and for the location \times week interaction ($F=1.33$; $df=48, 181.3$; $P=0.0913$), PROC GLIMMIX (SAS Institute 2013).

Table 6. Male *C. capitata* and *B. dorsalis* captures (mean \pm SEM flies per trap) in Jackson traps (1 h) with Mallet TMR dispensers with DDVP or Vaportape weathered at Exeter or Riverside, CA, locations (24 July–18 September 2012) and bioassayed at Kauai Coffee Plantation, Numila, HI (3–10 December 2012)

Species	Fresh	1 wk	2 wk	3 wk	4 wk	5 wk	6 wk	7 wk	8 wk
<i>C. capitata</i>	63.4 \pm 8.5	65.2 \pm 8.7	60.7 \pm 8.2	44.3 \pm 6.0	43.5 \pm 5.9	38.2 \pm 5.2	37.2 \pm 5.1	29.0 \pm 4.0	23.8 \pm 3.3
<i>B. dorsalis</i>	6.6 \pm 1.9	5.0 \pm 1.5	4.3 \pm 1.3	4.0 \pm 1.3	3.5 \pm 1.1	3.4 \pm 1.1	3.3 \pm 1.1	2.2 \pm 0.8	1.4 \pm 0.6

Mean (\pm SEM) *C. capitata* per trap: Exeter: DDVP = 45.8 \pm 4.5; Vaportape = 60.7 \pm 5.9; Riverside: DDVP = 39.0 \pm 3.8; Vaportape = 30.8 \pm 3.1. Mean (\pm SEM) *B. dorsalis* per trap: Exeter: DDVP = 3.6 \pm 1.6; Vaportape = 2.9 \pm 1.4; Riverside: DDVP = 4.3 \pm 1.9; Vaportape = 3.5 \pm 1.6. Captures of *C. capitata* and *B. dorsalis* by week.

For *C. capitata*, there were significant differences for location ($F=19.98$; $df=1, 12$; $P=0.0008$), week ($F=7.81$; $df=8, 96$; $P<0.0001$), and for the location \times treatment interaction ($F=7.67$; $df=1, 12$; $P=0.0170$); no significant differences were observed for the other fixed effects in the model. For *B. dorsalis*, significant differences were seen for week ($F=3.76$; $df=8, 96$; $P=0.0007$); no significant differences were observed for the other fixed effects in the model, PROC MIXED (SAS Institute 2013).

interaction ($F=7.67$; $df=1, 12$; $P=0.0170$; Table 6). For *B. dorsalis*, significant differences were found only for week ($F=3.76$; $df=8, 96$; $P=0.0007$). Mean (\pm SEM) *C. capitata* per trap were Exeter: DDVP = 45.8 \pm 4.5; Vaportape = 60.7 \pm 5.9; Riverside: DDVP = 39.0 \pm 3.8; Vaportape = 30.8 \pm 3.1. Mean (\pm SEM) *B. dorsalis* per trap were Exeter: DDVP = 3.6 \pm 1.6; Vaportape = 2.9 \pm 1.4; Riverside: DDVP = 4.3 \pm 1.9; Vaportape = 3.5 \pm 1.6. Captures of *C. capitata* and *B. dorsalis* by week are summarized in Table 6. For *B. cucurbitae*, significant differences were found for week ($F=2.18$; $df=8, 96.76$; $P=0.0355$), and the location \times week interaction ($F=2.14$; $df=8, 96.76$; $P=0.0394$; Table 7). For the winter (8 January–2 April 2013) insecticide weathering trials at Exeter and Riverside, few significant differences were observed for *C. capitata* and *B. dorsalis* (Table 8) and *B. cucurbitae* (Table 9).

Discussion

In the current study, no significant differences were observed in captures of fruit flies even when dispensers were weathered in five different locations of California. Captures of *C. capitata*, *B. cucurbitae*, and *B. dorsalis* in traps baited with Mallet TMR

treatments impregnated with DDVP did not significantly differ by location during both winter and summer trials. These data provide additional information on lure effectiveness weathered in different counties across California that experience variable environmental conditions and fruit fly infestations. The dispensers would be expected to be affected similarly no matter where in southern California the traps are deployed. This would mean they would be similarly affected in all parts of California (CDFA 2013). Further understanding of the degradation of male-specific lures in a proprietary polymer matrix via chemical analysis will provide empirical evidence on the duration of lure effectiveness, the effects of climate, and their relationship to fruit fly attraction (Vargas et al. 2015; Vargas et al. 2015 unpublished). Besides the environmental benefits, consolidating detection traps would reduce labor and material costs associated with deployment of numerous traps, which is the biggest expense of large survey programs. In 2005, the cost of surveillance in Florida, Texas, and California was US\$11 million, US\$1.8 million, and US\$20 million, respectively (USDA-APHIS 2006).

Similarly, with respect to solid insecticides, Vargas et al. (2009) found insecticides had to be used, but no difference between captures of *B. dorsalis* and *B. cucurbitae* with DDVP Vaportape and

Table 7. Male *B. cucurbitae* captures (mean \pm SEM flies per trap) in Jackson traps (24 h) with Mallet TMR dispensers with DDVP or Vaportape weathered in Exeter or Riverside, CA, locations (24 July–18 September 2012) and bioassayed at Kauai Coffee Plantation, Numila, HI (3–10 December 2012)

Location	Fresh	1 wk	2 wk	3 wk	4 wk	5 wk	6 wk	7 wk	8 wk
Exeter	1.54 \pm 0.62	0.30 \pm 0.38	0.66 \pm 0.43	0.54 \pm 0.41	0.16 \pm 0.33	0.40 \pm 0.38	-0.04 \pm 0.27	0.30 \pm 0.38	0.73 \pm 0.45
Riverside	0.90 \pm 0.49	0.55 \pm 0.41	0.07 \pm 0.30	0.90 \pm 0.49	0.88 \pm 0.48	1.01 \pm 0.51	0.24 \pm 0.0	1.95 \pm 0.8	0.31 \pm 0.35

Significant differences were observed for week ($F=2.18$; $df=8$, 96.76; $P=0.0355$), and the location \times week interaction ($F=2.14$; $df=8$, 96.76; $P=0.0394$); no significant differences were seen for treatment ($F=0.68$; $df=1$, 14.09; $P=0.4228$), location ($F=0.57$; $df=1$, 14.09; $P=0.4645$), location \times treatment interaction ($F=0.22$; $df=1$, 14.09; $P=0.6455$), treatment \times week interaction ($F=1.41$; $df=8$, 96.76; $P=0.2012$), and location \times treatment \times week interaction ($F=0.78$; $df=8$, 96.76; $P=0.6249$), PROC GLIMMIX (SAS Institute 2013).

Table 8. Male *C. capitata* or *B. dorsalis* captures (mean \pm SEM flies per trap) in Jackson traps (1 h) with Mallet TMR dispensers with DDVP or Vaportape weathered in Exeter or Riverside, CA, locations (8 January–2 April 2013) and bioassayed at Kauai Coffee Plantation, Numila, HI (18–22 November 2013)

Species	Fresh	1 wk	2 wk	3 wk	4 wk	5 wk	6 wk	7 wk	8 wk	9 wk	10 wk	11 wk	12 wk
<i>C. capitata</i>	7.7 \pm 2.0	65.2 \pm 15.0	60.7 \pm 13.9	44.3 \pm 10.2	43.5 \pm 10.0	38.2 \pm 8.9	37.2 \pm 8.6	29.0 \pm 6.8	23.8 \pm 5.6	6.4 \pm 1.7	7.2 \pm 1.9	10.3 \pm 2.5	6.6 \pm 1.7
<i>B. dorsalis</i>	12.4 \pm 5.1	8.7 \pm 3.7	11.5 \pm 4.8	11.3 \pm 4.7	7.2 \pm 3.1	7.2 \pm 3.1	7.9 \pm 3.4	7.2 \pm 3.1	11.1 \pm 4.6	9.3 \pm 3.9	6.7 \pm 2.9	8.1 \pm 3.5	9.5 \pm 4.0

For *C. capitata*, significant differences were observed for week ($F=24.95$; $df=12$, 144; $P<0.0001$); no significant differences were seen for treatment ($F=0.12$; $df=1$, 12; $P=0.7328$), location ($F=1.52$; $df=1$, 12; $P=0.2412$), location \times treatment interaction ($F=0.69$; $df=1$, 12; $P=0.4222$), location \times week interaction ($F=0.83$; $df=12$, 144; $P=0.6196$), treatment \times week interaction ($F=0.23$; $df=12$, 144; $P=0.9968$), and location \times treatment \times week interaction ($F=0.46$; $df=12$, 144; $P=0.9361$); for *B. dorsalis*, no significant differences were seen for treatment ($F=0.22$; $df=1$, 12; $P=0.6507$), location ($F=0.07$; $df=1$, 12; $P=0.7892$), week ($F=1.21$; $df=12$, 144; $P=0.2831$), location \times treatment interaction ($F=0.0$; $df=1$, 12; $P=0.9790$), location \times week interaction ($F=0.78$; $df=12$, 144; $P=0.6747$), treatment \times week interaction ($F=0.97$; $df=12$, 144; $P=0.4826$), and location \times treatment \times week interaction ($F=1.24$; $df=12$, 144; $P=0.2638$), PROC MIXED (SAS Institute 2013).

Table 9. Male *B. cucurbitae* captures (mean \pm SEM flies per trap) in Jackson traps (24 h) with Mallet TMR dispensers weathered at Exeter or Riverside, CA (8 January–2 April 2013), and bioassayed at Kauai Coffee Plantation, Numila, HI (18–22 November 2013)

Insecticide system	Fresh	1 wk	2 wk	3 wk	4 wk	5 wk	6 wk	7 wk	8 wk	9 wk	10 wk	11 wk	12 wk
DDVP	1.83 \pm 0.62	0.35 \pm 0.36	0.95 \pm 0.47	0.35 \pm 0.36	0.45 \pm 0.39	0.60 \pm 0.41	0.60 \pm 0.41	0.97 \pm 0.49	0.60 \pm 0.41	0.48 \pm 0.21	0.35 \pm 0.36	0.19 \pm 0.34	0.10 \pm 0.36
Vaportape	1.15 \pm 0.51	1.31 \pm 0.52	0.89 \pm 0.47	1.59 \pm 0.58	0.24 \pm 0.34	0.24 \pm 0.34	0.80 \pm 0.45	0.35 \pm 0.36	1.34 \pm 0.52	1.97 \pm 0.61	0.35 \pm 0.36	0.59 \pm 0.53	0.41 \pm 0.43

No significant differences were observed for treatment ($F=1.47$; $df=1$, 13.38; $P=0.2464$), location ($F=0.46$; $df=1$, 13.38; $P=0.7872$), week ($F=1.57$; $df=12$, 143.6; $P=0.1078$), location \times treatment interaction ($F=0.08$; $df=1$, 13.38; $P=0.9790$), location \times week interaction ($F=0.54$; $df=12$, 143.6; $P=0.8830$), treatment \times week interaction ($F=1.60$; $df=12$, 143.6; $P=0.0978$), and location \times treatment \times week interaction ($F=1.0$; $df=12$, 143.6; $P=0.4566$), PROC GLIMMIX (SAS Institute 2013).

liquid naled as used in Jackson traps for detection programs in California and Florida. Subsequent studies by Shelly et al. (2013) confirmed these results. In recent chemical studies, degradation of DDVP was described effectively by asymptotic nonlinear regression curves, whereby the amount of DDVP in the dispenser decreased rapidly over the first 3 wk of weathering and then more slowly (Vargas et al. 2015). Jang (2010) estimated the effective longevity of Vaportape II to be ~ 25 d in a fruit fly trap, although insect kill occurred for a much longer period. Some differences in capture were also noted between traps with DDVP Vaportape and traps without an insecticide, apparently due to repellency or more likely due to flies dying outside the trap during certain trapping periods (Jang 2010). In the present study, there appeared to be some differences in captures of *C. capitata* (but not *B. dorsalis* and *B. cucurbitae*) associated with Vaportape weathering site (Exeter vs. Riverside), possibly due to the effects of hotter temperatures and lower humidity in Exeter that caused greater loss of DDVP from Vaportape strips. Chemical analysis of the Vaportape strips did confirm faster loss of DDVP from those weathered in Exeter compared with Riverside (Vargas et al. 2015 unpublished data). Nonetheless, when bioassayed in Hawaii in coffee orchards with very high populations of

C. capitata, the sticky inserts with TMR dispensers with Vaportape weathered in Riverside appeared to capture fewer *C. capitata* during certain weeks, than those from Exeter. We suspect that higher emission of DDVP from Jackson traps weathered in Riverside caused many flies to either be repelled or die before landing inside the trap. One procedural modification would be to open DDVP packets 1–2 d before deployment. A second modification to the Jackson trap would be the addition of a swivel to hold the dispenser and Vaportape. Our results for DDVP Vaportape deployment inside Jackson traps for capture of *C. capitata* deserve more study. Nonetheless, there were few differences between TMR + Vaportape and TMR impregnated with DDVP. Implementation of insecticidal strips in place of liquid organophosphates (e.g., naled and malathion) would represent an important improvement from a worker acceptance and safety standpoint (Vargas et al. 2009). Results from the current studies at Exeter and Riverside suggest Vaportape could be used as a replacement for DDVP-impregnated wafers under California environmental conditions. This is an important finding, as inclusion of an insecticide in wafers (i.e., Mallet TMR wafers) would most likely require that the dispenser be registered with U.S. Environmental Protection Agency (EPA). However, a registration

already exists for Vaportape II strips, whereby they could be used with solid dispensers containing an approved lure inside a trap for either survey work or male annihilation in an IPM program, without the further expense of registering a new lure insecticide combination (i.e., a lure impregnated with DDVP).

In conclusion, the present study in five California locations and two earlier studies in Hawaii (Shelly 2012, Vargas et al. 2012) suggest that traps baited with a solid formulation containing three lures (TML, ME, and RK plus the toxicant DDVP = Mallet TMR), but with a high concentration of ME and a large dispenser surface area, could be used in large survey programs for detection of fruit flies. These solid wafers are safer and more convenient to handle, and may be used in place of several individual lure and trap systems, thus reducing the costs of large survey and detection programs in California and Florida (Florida Department of Agriculture and Consumer Services [FDACS] 2004). TMR dispensers for use as male annihilation technique (MAT) devices will be tested further in Hawaii in escape proof traps without an insecticide (Jang 2010)

Acknowledgments

We thank Russell Ijima, Charmaine D. Sylva, Yu Nakane, Dominique Easter-Green, Jacqueline De La Garza, Daisy L. Willis, and Jordan “Kama” Lee Loy (Daniel K. Inouye Pacific Basin Agricultural Research Center, USDA-ARS, Hilo, HI) for data collection and logistical support in Hawaii. We also thank Lindsay J. Robinson, Monica J. Dimson, Stephanie M. Rill, Anita M. Hunt, Sara Scott, Jamie Nemecek, Jennifer Ruvalcaba, Therese Kapaun, Leah Haynes, Beryl Feller, Lee Rosenboom, Rebecca Montgomery, and Marian Fleming for logistical and experimental support in California. We thank the University of California Agriculture and Natural Resources Lindcove Research and Extension Center, UC ANR Lindcove Research and Extension Center, and Hansen Research and Extension Center in California for providing access to citrus groves for trap weather. We also thank A&B Properties, Kauai Coffee Co., and in particular, Greg Williams, for allowing us to use sections of their coffee plantation for evaluations. We thank Nicholas Manoukis and John Stark for comments on an earlier drafts of this manuscript. Finally, we thank the California Citrus Research Board (5500-193) and IR-4 (2013-34383-20981) for partial financial support for this work.

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