Research Article

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Comparative effectiveness of food-based attractants in capturing tephritid fruit flies (Diptera: Tephritidae): results from field trials in Florida, Guatemala, and Hawaii

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Abstract: Many countries operate trapping programs to detect incursions of tephritid fruit fly pests (Diptera: Tephritidae). Food-based attractants are an important component of trapping systems, as they are neither species- nor sex-specific. Liquid protein baits, including an aqueous solution of torula yeast plus borax (TYB), have traditionally been used. However, such baits are short-lasting and must be replaced frequently. Several dry, synthetic food baits, all containing ammonium acetate, putrescine, and trimethylamine hydrochloride, have been developed as potential replacements for TYB. A recent study reported that, in five different countries, a new vial-lure dispenser (containing these same three components) attracted similar or greater numbers of Mediterranean fruit flies, *Ceratitis capitata* (Wiedemann), than TYB-baited traps. In all locations the TYB was replaced weekly, while the vial-lures were not replaced over eight consecutive weeks of trapping. Here, we present additional data from three different regions on the performance of vial-lure dispensers relative to TYB and several other synthetic food-based lures. Results from Florida and Guatemala showed that traps baited with vial-lures captured an equivalent or greater number of *C. capitata* as traps baited with TYB, whereas in Hawaii TYB was significantly more attractive than the vial-lures. No consistent differences were evident between vial-lures and the other synthetic food baits tested. The present study does not identify the most effective replacement for TYB for monitoring *C. capitata*. Regardless of the specific bait used, however, the extended field longevity characteristic of synthetic food-based attractants will reduce the high servicing costs associated with TYB-baited traps.

Keywords: detection; invasive species; Mediterranean fruit fly; trapping; food baits

Resumen: Muchos países implementan programas de trampeo para detectar incursiones de moscas de la fruta tefrítidas (Diptera: Tephritidae). Los atrayentes alimentarios son un componente importante de los sistemas de trampeo, ya que no son específicos de la especie ni del sexo. Tradicionalmente se han utilizado cebos proteicos líquidos, que incluyen una solución acuosa de levadura torula con bórax (TYB). Sin embargo, estos cebos son de corta duración y deben reemplazarse con frecuencia. Se han desarrollado varios cebos alimenticios sintéticos secos, todos ellos con acetato de amonio, putrescina e hidrocloruro de trimetilamina, como posibles sustitutos del TYB. Un estudio reciente informó que, en cinco países diferentes, un nuevo dispensador de viales-cebo (que contenía estos mismos tres componentes) atrajo cantidades similares o mayores de moscas

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de la fruta mediterráneas, *Ceratitis capitata* (Wiedemann), que las trampas con cebo TYB. En todos los lugares, el TYB se reemplazó semanalmente, mientras que los viales-cebo no se reemplazaron durante ocho semanas consecutivas de captura. Aquí presentamos datos adicionales de tres regiones diferentes sobre el rendimiento de los dispensadores de viales-cebo en comparación con el TYB y otros cebos sintéticos a base de alimento. Los resultados de Florida y Guatemala mostraron que las trampas con viales-cebo capturaron una cantidad equivalente o mayor de *C. capitata* que las trampas cebadas con TYB, mientras que en Hawaii el TYB fue significativamente más atractivo que los viales-cebo. No se observaron diferencias consistentes entre los atrayentes viales y los demás cebos sintéticos probados. El presente estudio no identifica el sustituto más eficaz del TYB para el monitoreo de *C. capitata*. Sin embargo, independientemente del cebo específico utilizado, la prolongada longevidad, en el campo, característica de los atrayentes sintéticos a base de alimento reducirá los altos costos de mantenimiento asociados con las trampas con cebo TYB.

Palabras clave: detección; especies invasoras; mosca mediterránea de la fruta; trampas; cebos alimentarios

1 Introduction

Invasive fruit flies (Diptera: Tephritidae) pose a global threat to the production and transport of many important fruit and vegetable crops (Papadopoulos et al. 2024). The fruit and vegetable industry in the United States, valued at 48 billion USD (Huang et al. 2022), is particularly vulnerable to these pests. Given this threat, many countries operate continuous, large-scale trapping networks to detect incursions of tephritid pests (Kean et al. 2024; Lasa et al. 2024). Trapping relies largely on so-called male lures, which are natural or synthetic compounds attractive, as the name implies, to males only (Tan et al. 2014). While powerful attractants, the male lures have limitations, because (i) they are taxon-specific, attractive only to males of a particular genus or closely related genera, (ii) males of many tephritid species are not responsive to known lures, and (iii) females, presumably half of any incipient population, are excluded as targets of detection programs.

Given these constraints, surveillance efforts generally include food-based baits, which are broadly attractive to both sexes of all tephritid species, although a female bias in captures is often noted (Miranda et al. 2001; Leblanc et al. 2010), and species vary in their attraction to different food baits (Thomas et al. 2008). Compared to male lures, however, food baits are considered weak attractants (Epsky et al. 2014; Shelly 2021). For example, in mark-release-recapture trials, a trap baited with the male lure methyl eugenol captured 55 % of *Bactrocera dorsalis* (Hendel) males released 25 m from the trap, whereas <1 % of *B. dorsalis* males and females were trapped following their release 20 m from a food-baited trap (Shelly 2021; Shelly et al. 2010). Moreover, one of the most widely used food baits, an aqueous solution of torula yeast and borax (TYB), requires refreshing or replacing every 1–2 weeks due to the rapid deterioration of the product (FAO/IAEA 2018), which, in turn, imposes high labor costs.

To avoid frequent replacement, a dry, synthetic food-based lure was developed in the 1990s by Heath and his colleagues (Epsky et al. 1995; Heath et al. 1995, 1997). The lure, marketed as BioLure® (Suterra, LLC, Bend, Oregon, USA), consisted of three components, ammonium acetate, putrescine, and trimethylamine hydrochloride, originally deployed in individual sachets within the trap. An international study (Epsky et al. 1999), involving trapping in seven different countries, showed that traps baited with the three-component BioLure®, presented in three separate pouches, captured similar numbers of Mediterranean fruit flies (medfly), *Ceratitis capitata* (Wiedemann), as a commonly used liquid protein bait. In that study, trapping was conducted over 8 weeks, with the liquid protein bait replaced weekly and the BioLure® replaced once at the 4-week midpoint. This seminal study stimulated much additional fieldwork comparing BioLure®, with the three components presented individually, with more traditional liquid protein lures (Broughton and De Lima 2002; Conway and Forrester 2007; Epsky et al. 2011; Gazit et al. 1998; Grout et al. 2011; Hall et al. 2005; Holler et al. 2006; Katsoyannos et al. 1999; Leblanc et al. 2010; Manrakhan et al. 2017; Martinez et al. 2007; Miranda et al. 2001; Thomas et al. 2008). As part of this research, several studies (Epsky et al. 2011; Holler et al. 2006) demonstrated that a two-component version of BioLure®, that lacked trimethylamine hydrochloride, was more effective for *Anastrepha* spp. than the three-component bait. Although the results were not uniform, these studies (i) generally found, consistent with Epsky et al. (1999), that three-component BioLure® was equally or even more attractive than liquid protein baits to *C. capitata* (e.g., Gazit et al. 1998; Broughton and De Lima 2002; Miranda et al. 2001) and (ii) provided inconsistent results for *Anastrepha* species, with the two-component BioLure® outperforming liquid protein bait in certain studies (Hall et al. 2005; Martinez et al. 2007) but not in others (Pingel et al. 2006; Thomas et al. 2008). Eventually, a new, more convenient formulation of the three-component BioLure® was developed that presented all compounds in a single sachet, and several studies (Holler et al. 2009; Navarro-Llopis et al. 2008) confirmed that this single sachet formulation was as attractive to *C. capitata* as the three separate sachets.

Given the effectiveness of BioLure®, different companies subsequently developed food baits that used the same components but in different absolute and relative amounts. Also, although much of this information is proprietary, it appears that different materials are used as a matrix to contain and dispense the compounds. In one obvious instance, the attractants are not held in a sachet at all but have been embedded in a polymeric conical device, termed a food cone (Shelly et al. 2023; Scentry Biologicals Inc., Billings, Montana, USA). Various studies (e.g., Navarro-Llopis et al. 2008; Thomas et al. 2008; Manrakhan et al. 2017; Shelly and Fezza 2024) have compared the field performance of different synthetic food baits, but the collective results are difficult to interpret, because (i) the set of lures tested varied among studies, (ii) a liquid protein bait was not always included as a standard, (iii) the species targeted varied among studies, and (iv) data were collected under varying environmental conditions.

A recent study (Enkerlin et al. 2025) focused on a new type of dispenser, termed a vial-lure, that contains the same components as BioLure® embedded in a novel gel formulation. Vial-lure was developed by the Agricultural Research Service of the United States Department of Agriculture (USDA-ARS) and is available as single (separate) vial formulations of ammonium acetate, putrescine, and trimethylamine hydrochloride or as a combined formulation with the three components in the same vial. Data from several Central and South American countries, along with Hawaii, showed that captures of *C. capitata* in traps baited with three-component vial-lures were equal to or greater than traps baited with TYB (Enkerlin et al. 2025). Importantly, while the TYB was replaced weekly, the vial-lures were not replaced over eight consecutive weeks of trapping. In many of the studies cited above, the BioLure® was replaced at 3–5-week intervals (e.g., Heath et al. 1995; Epsky et al. 1999; Mwatawala et al. 2006) and/or not compared with standard liquid protein bait (e.g., Navarro-Llopis et al. 2008; Holler et al. 2009), and thus its effective field longevity has not been well-documented. The long-lasting potency of the vial-lure dispenser makes it an attractive option for large-scale detection programs.

The objective of the present study was to gather additional data on the performance of vial-lure dispensers relative to TYB solution as well as several other commercially available, synthetic food-based lures in capturing medfly. Field work was conducted in Florida with released, sterile male medflies, Hawaii with wild medflies, and Guatemala with both released, sterile males and wild medflies. In Hawaii, data on *B. dorsalis* were gathered as well. All locations used the same type of trap and similar sets of food lures and followed a similar protocol regarding lure replacement and trap servicing. However, trapping was conducted in vastly different habitats among the three locations, namely urban and residential areas in Florida, coffee (*Coffea arabica* L.; Rubiaceae) fields in Hawaii, and citrus and coffee fields in Guatemala, thus allowing evaluation of the vial-lures under different environmental conditions.

2 Materials and methods

2.1 Traps

All food baits were placed in Multilure traps (Better World Manufacturing Inc., Fresno, California, USA), which are two-piece, plastic McPhail-like traps (FAO/IAEA 2018). The top portion is clear, while the bottom is bright yellow and holds liquid food bait or preservative (as described below). A capped, slitted well (2.8 cm diameter, 5.0 cm depth) extends inwards from the top portion and may be used to hold solid baits. The bottom of the trap has a central, open invagination through which bait odors are emitted and insects enter. The liquid-filled reservoir acts as the killing mechanism. A wire hanger at the top of the trap is used to suspend the trap from tree branches.

2.2 Lures

Different sets of food lures were tested at the different locations (Table 1). The synthetic food baits (i.e., all except TYB) contained the same three components, ammonium acetate, trimethylamine hydrochloride, and putrescine (free-base or dihydrochloride salt). Where disclosed by the manufacturers, the relative amounts of the three components followed the same trend: ammonium acetate > trimethylamine hydrochloride > putrescine, although the exact proportions of the components appeared to vary among dispensers. In addition, the size, shape, and composition of the solid carrier matrix varied as well (as described below). Given its short-term effectiveness in the field (FAO/IAEA 2018), TYB was replaced over the course of trapping in all three locations, whereas all other baits were used over the entire course of trapping and were not replaced after deployment.

(1) Torula yeast borax (TYB) solution. This bait has been widely used in tephritid trapping programs worldwide (Heath et al. 1995). The preparation of TYB varied slightly among the three locations. In Hawaii, TYB was prepared by dissolving one TYB pellet (5 g; Scentry Biologicals Inc., Billings, Montana, USA) per 100 mL of a water/antifreeze solution (90:10 v:v; SPLASH RV and

Marine Antifreeze, SPLASH Products Inc., St. Paul, Minnesota, USA), and individual traps were baited with 300 mL of the solution. In Florida, one TYB pellet was used per 100 mL of water (i.e., no antifreeze was used), and individual traps contained 400 mL of the solution. In Guatemala, three TYB pellets were used per 200 mL of water (as with Florida, no antifreeze was used), and each trap was baited with 200 mL of the solution.

(2) Food cones. These devices from Scentry Biologicals Inc. (Billings, Montana, USA) were solid, conically shaped dispensers (height 5 cm, base diameter 2 cm) that were placed in the slatted well built into the top of the trap. Once the food cone was in place, the well was capped on top, and odors from the food cone were emitted via the opening on the bottom of the trap (like all other lures tested). For all synthetic food baits, including food cones, an aqueous solution of antifreeze was placed in the reservoir of traps. In Hawaii, the antifreeze SPLASH was used, and 300 mL of the water-antifreeze solution (90:10 v:v) were placed in individual traps. In Florida, Prestone Low-Tox antifreeze (Lake Forest, Illinois, USA) was used, and 400 mL of the water-antifreeze mixture (90:10 v:v) were placed in individual traps. In Guatemala, a different ratio of water:-antifreeze was employed (67:33 v:v; Prestone Low-Tox antifreeze was used), and 200 mL of this solution were placed in traps. The performance of food cones is of particular interest, because these devices are currently used in fruit fly detection programs in Florida and Texas.

(3) 1-1-1 vial-lures. These devices from Better World Manufacturing, Inc. (Fresno, California) were comprised of three separate thermoplastic cylindrical vials (45 mm height, 20 mm diameter) each of which contained a gel-based formulation of one of the components common to all synthetic food baits tested here. With this bait, the three vial-lures were held in a transparent plastic carousel affixed to the inner top of the Multilure trap above the reservoir.

(4) 3-in-1 vial-lures. These devices from Better World Manufacturing, Inc. (Fresno, California) were thermoplastic cylindrical vials (58 mm height, 20 mm diameter) each of which contained all three of the components characteristic of the synthetic food baits. With this bait, a single vial-lure was held in a plastic carousel as described above.

(5) Difusors. These devices from Susbin SA (Mendoza, Argentina) were plastic pouches, or sachets (10 × 6 cm rectangles), that had an opening on one side to allow release of the odor and were suspended inside the Multilure trap by a hook affixed to the top of the trap.

Table 1: Food baits tested for capturing tephritid fruit flies in the three study locations.

	Location			
	Florida	Hawaii	Guatemala	
Food baits	2023	2023	2017	2024
Torula yeast borax	+	+	+	–
Food cone	+	+	+	+
1-1-1 vial-lure	+	+	+	+
3-in-1 vial-lure	+	+	–	–
Difusor	–	+	–	–
Unipak	–	–	+	+
CT	–	–	–	+

'+' denotes tested, and '–' denotes not tested.

(6) Unipaks. These units from Suterra (Bend, Oregon) were plastic sachets (9.5 cm squares) that had an opening on one side to allow release of the odor and were suspended inside the Multilure trap by clips affixed to the top of the trap.

(7) CTs. These devices, manufactured by ChemTica [CT] Intl. SA (Heredia, Costa Rica) were sachets (10 × 7 cm rectangles) comprised of two chambers, which held ammonium acetate and trimethylamine separately, and an attached bubble containing putrescine. Each chamber had an opening on one side to allow release of the odor, and the putrescine bubble was activated by a puncture with a pin. The sachets were suspended inside the Multilure trap by a hook affixed to the top of the trap.

2.3 Study sites and trapping protocol

2.3.1 Florida

Field work was conducted during April to July, 2023, in suburban, residential areas of Tampa, Florida, USA. Average daily minimum and maximum temperatures for the days included in the study period were 23.8 °C (range: 17.2–27.8 °C) and 31.9 °C (range: 26.7–36.1 °C), respectively (based on data for Tampa International Airport, https://www.wunderground.com/KTPA). A total of 15 experimental plots, each 1 mile^2 (2.6 km^2), were used. The plots were distributed over an area of 53.4 km^2 east and northeast of the Tampa International Airport. Within a plot, traps were generally placed in areas with single-family houses occupying small lots that contained lawns, ornamental shrubs, and shade and fruit trees. All traps were contained within the area treated by the Sterile Mediterranean Fruit Fly Preventative Release Program (PRP) operated by the United States Department of Agriculture Animal and Plant Health Inspection Service (USDA-APHIS 2014). Wild Mediterranean fruit flies are absent from Florida, and, if detected, immediately prompt eradication efforts. Consequently, data were gathered for sterile males used in the ongoing PRP. Twenty-two releases were made by airplane over the trapping area during the 10-week study, with an average of 109,000 sterile males released per mile^2.

One trap per treatment was placed in each of the 15 plots (=60 total traps). Within individual plots, traps were separated by >150 m. The same trap sites (trees) were used over the entire study, and bait treatments were rotated among trap sites between successive trapping periods. With only three exceptions, traps were placed in host plants of *C. capitata*, including loquat (*Eriobotyra japonica* (Thunb.) Lindl.; Rosaceae), mango (*Mangifera indica* L.; Anacardiaceae), avocado (*Persea americana* Mill.; Lauraceae), longan (*Dimocarpus longan* Lour.; Sapindaceae), and sour orange (*Citrus aurantium* L.; Rutaceae). Collectively, loquat and mango represented 85 % (51/60) of all sites.

2.3.2 Guatemala

Trapping in Guatemala was conducted in 2017 and 2024 with different food baits tested in the 2 years (Table 1). In 2017, trapping was conducted over a 10-week period during July to September at a citrus farm (Finca Pastoria) about 10 km west of the municipality of Barberena (1,000 m a.s.l.). Ripe fruit were present on trees over much of this period. During this period, the daily minimum and maximum temperatures averaged 17.7 °C (range: 15.7–19.2 °C) and 28.9 °C (range: 25.3–31.6 °C), respectively (data derived from Pro2 Vantage Outdoor Weather Station, Davis Instruments, Hayward, California, USA). Tree rows were separated by 5 m, and trees within a row were 4 m apart. In 2017, one trap of each treatment was placed in each of 12 rows of citrus trees (i.e., 48 traps total). Tree rows with traps were 25 m apart, and traps within the same row also were separated by 25 m. Both wild and released sterile male *C. capitata* were trapped in 2017. The sterile males were from a *tsl* genetic sexing strain mass-reared in El Pino, Guatemala (Rendón and Enkerlin 2021) and were released by ground at a rate of 167,000 males per km^2. Owing to unknown factors, relatively few sterile males were trapped during weeks 1–5 of the study period, consequently data on sterile males were included only for weeks 6–10.

In 2024, trapping was conducted over a 10-week period during March to June in a coffee field (Finca Cafetalera) near Antigua (1,530 m a.s.l.). Plants bore no flowers or fruits during the study period. During this period, the daily minimum and maximum temperatures averaged 14.4 °C (range: 9.6–19.2 °C) and 25.8 °C (range: 23.4–28.8 °C), respectively (Pro2 Vantage Outdoor Weather Station). Coffee rows were separated by 2 m, and plants within a row were 1.5 m apart. One trap of each treatment was placed in each of five rows of coffee plants (i.e., 20 traps total). Coffee rows with traps were 20 m apart, and traps within the same row were also 20 m apart. No sterile males were released at the 2024 study site, and captures included wild *C. capitata* males exclusively.

2.3.3 Hawaii

In Hawaii, field work was conducted in a coffee field (*C. arabica*; area 65 ha, elevation 90 m) in central Oahu approximately 10 km southeast of Haleiwa, Hawaii. Plants were 2–4 m tall and were grown in rows spaced 2–3 m apart. Within a row, trunks of the individual plants were separated by 1–2 m, and foliage generally overlapped between adjacent plants. Trapping was conducted from September through November 2023, with wild populations of *C. capitata* and *B. dorsalis* captured in large enough numbers for analysis. Coffee serves as a host for both these species, and additional hosts, such as papaya (*Carica papaya* L.; Caricaceae), mango (*M. indica*), and lychee (*Litchee chinensis* Sonn.; Sapindaceae) (EPPO 2025) were present near the coffee field. Average daily minimum and maximum temperatures over this interval were 23.4 °C (range: 22.2–25.5 °C) and 29.8 °C (range: 26.1–32.2 °C), respectively (Wheeler Army Airfield, Wahiawa, Hawaii, approximately 10 km from the site; National Weather Service https://forecast.weather.gov/data/obhistory/PHHI.html).

Ten traps were used for each treatment (i.e., 50 total traps), with one trap/treatment placed in each of 10 plant rows. Within a row, neighboring traps were separated by 15–20 m, and trap-bearing rows were spaced 12–18 m apart. Treatment positions within rows were randomized for each sampling period. Because harvesting operations often damaged traps, trapping was conducted in different areas of the coffee field for each weathering interval.

2.4 Trap servicing

2.4.1 Florida and Guatemala

In Florida and Guatemala, Multilure traps were operated continuously for 10 weeks. Traps were placed in shaded positions in the canopy of host plants (with three exceptions in Florida as above) at 2 m above ground. In Florida, TYB-baited traps were serviced weekly; all other trap types were serviced on a biweekly basis (i.e., 2, 4, 6, 8, and 10 weeks post-deployment). In Guatemala, all traps were serviced on a weekly basis. During trap servicing, the captured insects were collected by pouring the liquid through a sieve to retain the catch. The TYB solution was replaced, while the aqueous antifreeze solution (contained in all non-TYB-baited traps) was topped up to 400 mL (Florida) or 200 mL (Guatemala). Traps were rotated to new positions for the next sampling interval to avoid positional bias. Sieved insects were returned to the laboratory for identification and counting. To clarify, in Florida TYB was replaced (and captured insects were collected), not only during the 2-week servicing of all traps, but also in alternate weeks between the biweekly servicing. For the TYB-baited traps, weekly counts were combined to produce a 2-week total (e.g., weeks 0–1 and 1–2 were added to yield captures for 0–2 weeks).

2.4.2 Hawaii

In Hawaii, traps were deployed for 4–6 days at 3-week intervals. Trapping was conducted on week 0 (all baits fresh) and then on weeks 3, 6, 9, and 12 (when food cones, sachets, and vial-lures had been weathered). After a sampling bout, the dry, synthetic baits were transported to the USDA Fruit Fly Laboratory, Aiea (approximately 20 km from the study site) and weathered in a shaded, outdoor area under environmental conditions similar to the study site. During weathering, the baits were held in Multilure traps and suspended from a clothesline 2 m aboveground. No liquid was placed in the trap reservoir during weathering. Fresh TYB was prepared for each trapping period.

2.5 Statistical analysis

Captures in Hawaii and Guatemala included both sexes of wild flies, consequently for these locations we first compared female percentages of captured flies among traps containing different treatments. Female percentages (number of females/total captures × 100) were computed for traps having ≥10 wild individuals, pooled over all trapping periods for the individual treatments, and then compared using the Kruskal–Wallis test (test statistic H). Where no significant variation in female percentages was detected among the different food baits for Hawaii or Guatemala, captures of wild females and males were combined in comparing the different food treatments.

For all three locations, the analysis of capture data was in two parts. First, because the numbers of captured flies recorded over all trapping periods were found to be non-normally distributed, the data were analyzed using generalized linear models (GLM), with the Poisson distribution (log link function) and week and bait as main effects. The significance of these independent variables was tested using a likelihood ratio chi-square. Week had a significant effect on captures in all cases, which likely reflected (i) natural variation in the size of wild populations and/or (ii) variable environmental conditions, e.g., wind speed, that affected the ability of flies to orient toward and locate traps. Because the potential impact of these two factors was unknown, analyses focused on identifying differences among bait treatments. Pairwise comparisons between food bait treatments were made using the nonparametric Wilcoxon rank sum test, and z values were used to test significance (α = 0.05).

Second, the interaction term between main effects was significant in all analyses, indicating that the impact of one predictor on capture numbers was dependent on the value of the other predictor. Thus, to evaluate possible changes in the relative attractiveness of the different food baits across the different weathering intervals, GLM was performed separately for each of the trapping periods. As above, the Poisson distribution with the log link function was employed, and the Wilcoxon test was used to compare captures among the food baits (α = 0.05). GLMs were performed with JMP 14 software (SAS Institute, Cary, North Carolina, USA). All other analyses, as well as plotting, were completed using SigmaPlot 15 software (Grafiti LLC, Palo Alto, California, USA.)

3 Results

3.1 Florida

Analysis of the entire data set showed that both week (χ^2 = 209.4, df = 4, P < 0.001) and bait (χ^2 = 33.9, df = 3, P < 0.001) had significant effects on captures of *C. capitata* (Figure 1). The week by bait interaction term was also significant (χ^2 = 144.3, df = 12, P < 0.001). Based on the complete data set, there were no significant differences found in any of the pairwise comparisons among food baits, although captures with 1-1-1 lure-vials were marginally greater than captures with food cones or TYB (P = 0.06 in both cases).

Bait type was found to have a significant effect on the numbers of captures for each weathering interval (P < 0.05 for all weekly GLMs) except for week 10 (P = 0.13) when captures were low for all baits (Table 2). At week 2, food cones attracted significantly more *C. capitata* than TYB and 1-1-1 vial-lures; the other three food baits did not differ significantly from one another. After the initial trapping period, however, traps baited with food cones generally

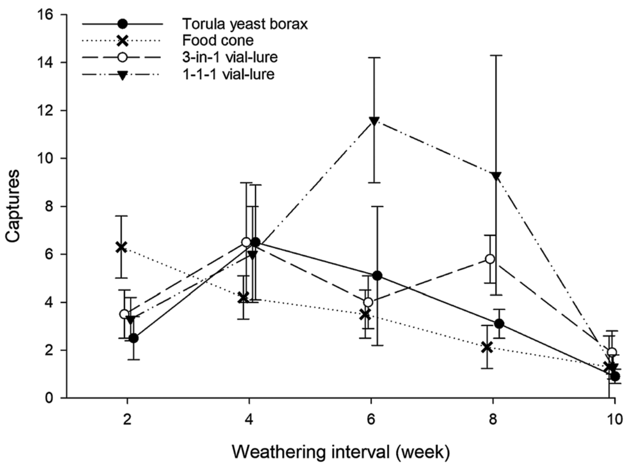

Figure 1: In Florida in 2023, captures of sterile males of the Mediterranean fruit fly, *Ceratitis capitata*, in Multilure traps baited with four food baits at varying weathering intervals of the dry synthetic baits (torula yeast borax was fresh for each trapping interval). Symbols represent mean captures (±1 SE) per trap per 2-week weathering period (N = 15 traps per treatment per period).

captured fewer flies than all other baits, although the differences were not always significant. Traps baited with vial-lures, particularly the 1-1-1 design, performed well at weeks 6 and 8, with 2–3 times as many captures as TYB or food cones at these intervals. Captures in vial-lure-baited traps and TYB- or food cone-baited traps were not significantly different at weeks 4 and 10, however, captures with 3-in-1 and 1-1-1 lure-vials were similar to or greater than captures with TYB.

Table 2: For Florida in 2023, results of pairwise comparisons (α = 0.05) of captures of released, sterile *Ceratitis capitata* males among the four food baits for the individual trapping periods based on the Wilcoxon rank sum test. Numerical averages and SE are presented in Figure 1.

	Week				
Food bait	**2**	**4**	**6**	**8**	**10**
Torula yeast borax	B [4]	A [1]	B [2]	AB [3]	A [4]
Food cone	A [1]	A [4]	B [4]	B [4]	A [3]
3-in-1 vial-lure	AB [2]	A [2]	B [3]	A [2]	A [1]
1-1-1 vial-lure	B [3]	A [3]	A [1]	A [1]	A [2]

For a given column, food baits sharing a letter were not significantly different. Bracketed numbers represent rank order of average captures per trap for a given interval, where 1 is highest and 4 is lowest. Over the entire data set (i.e., all weeks), there were no significant differences found in any of the pairwise comparisons among food baits, consequently the detailed results of those statistical analyses are not given here.

3.2 Guatemala

3.2.1 Year 2017

For captured wild Mediterranean fruit flies, female percentages (based on data from the entire trapping period) did not vary significantly among Multilure traps baited with food cones (average = 29 %, N = 14 traps), 1-1-1 vial lures (average = 21 %, N = 11 traps), or Unipaks (average = 19 %, N = 10 traps; H = 1.7, df = 2, P = 0.42). Only one trap baited with TYB captured ≥10 flies, consequently this bait was not included in the analysis.

For wild *C. capitata*, examination of the entire data set showed that both week (χ^2 = 434.4, df = 9, P < 0.001) and bait (χ^2 = 167.2, df = 3, P < 0.001) had significant effects on captures of *C. capitata* (Figure 2). The week by bait interaction term was also significant (χ^2 = 195.3, df = 27, P < 0.001). Based on data from all trapping periods, pairwise comparisons showed that captures of wild *C. capitata* in TYB-baited traps were significantly lower than any other treatment (Table 3). Captures with food cones were significantly greater than those with 1-1-1 vial-lures, while no significant differences were found between Unipaks and food cones or 1-1-1 vial-lures.

Bait type was found to have a significant effect on the numbers of captures for all weathering intervals except for weeks 5 and 10 when overall catch was low (Table 3). The same statistical pattern was observed in four of these eight weeks: captures of *C. capitata* were significantly greater in food cone- and Unipak-baited traps than in TYB-baited traps, and 1-1-1 vial-lure-baited traps had intermediate values that did not differ significantly from any other treatment.

For released, sterile Mediterranean fruit fly males, analysis of the entire data set showed that both week (χ^2 = 144.7, df = 4, P < 0.001) and bait (χ^2 = 435.3, df = 3, P < 0.001) had significant effects on captures of sterile *C. capitata* males (Figure 2). The week by bait interaction term was also significant (χ^2 = 50.3, df = 12, P < 0.001). Based on data from all trapping periods, pairwise comparisons showed that captures of *C. capitata* in TYB-baited traps were significantly lower than any other treatment and captures among the remaining three food baits did not differ significantly (Table 4).

Bait type was found to have a significant effect on the numbers of captures for all weathering intervals (Table 4). The same statistical pattern was observed in four of the five weeks analyzed: captures of sterile *C. capitata* males were significantly lower in TYB-baited traps than for any other food bait. In week 10, captures with TYB did not differ significantly from those with food cones but were lower than captures with 1-1-1 vial-lures or Unipaks.

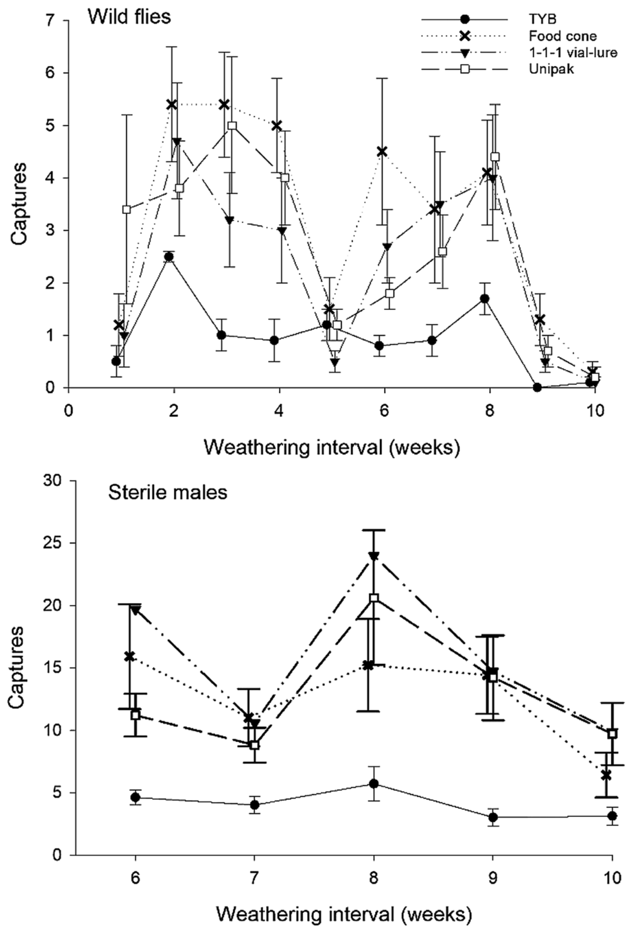

Figure 2: In Guatemala in 2017, captures of wild (sexes pooled) and sterile males of the Mediterranean fruit fly, *Ceratitis capitata*, in Multilure traps baited with four food baits at varying weathering intervals of the dry synthetic baits (TYB/torula yeast borax was fresh for each trapping interval). Symbols represent mean weekly captures (±1 SE; sexes combined) for individual traps (*N* = 12 per bait type per period).

3.2.2 Year 2024

Female percentages of wild *C. capitata* (based on data from the entire trapping period) did not vary significantly among Multilure traps baited with food cones (average = 42 %, $N = 15$ traps), 1-1-1 vial-lures (average = 47 %, $N = 28$ traps), Unipaks (average = 49 %, $N = 32$ traps), or CTs (average = 50 %, $N = 21$ traps; $H = 2.1$, $df = 3$, $P = 0.55$). These female percentages were substantially greater than those reported in 2017 (range: 19–29 % across food baits), which presumably reflected differences in the weather conditions and host plants between the two study sites.

Based on the entire data set, both week (χ^2 = 5,665.4, $df = 9$, $P < 0.001$) and bait ($\chi^2 = 402.4$, $df = 3$, $P < 0.001$) had significant effects on captures of *C. capitata* (Figure 3). The week by bait interaction term was also significant ($\chi^2 = 182.5$, $df = 27$, $P < 0.001$). Based on data from all trapping periods, pairwise comparisons showed that captures of *C. capitata* were significantly greater in Unipak-baited traps than in food cone- or CT-baited traps. 1-1-1 vial-lures also attracted more flies than food cones, but captures with 1-1-1 lure-vials were not statistically different from those with Unipaks or CTs (Table 5).

Bait type was found to have a significant effect on the numbers of captures for all weathering intervals (Table 5). Likely reflecting the small number of traps as well as high inter-trap variability in captures, however, pairwise

Table 4: For Guatemala in 2017, results of pairwise comparisons ($\alpha = 0.05$) of captures of released, sterile *Ceratitis capitata* males among the four food baits over all trapping periods and for the individual trapping periods based on the Wilcoxon rank sum test. Numerical averages and SE are presented in Figure 2.

		Week				
Food bait	**All**	**6**	**7**	**8**	**9**	**10**
Torula yeast borax	A	A [4]	A [4]	A [4]	A [4]	A [4]
Food cone	B	B [2]	B [1]	B [3]	B [2]	AB [3]
1-1-1 vial-lure	B	B [1]	B [2]	B [1]	B [1]	B [1]
Unipak	B	B [3]	B [3]	B [2]	B [3]	B [2]

For a given column, food baits sharing a letter were not significantly different. Weeks 1–5 were excluded, as sterile males were captured in very low numbers during this period. Bracketed numbers represent rank order of average captures per trap for a given interval, where 1 is highest and 4 is lowest.

Table 3: For Guatemala in 2017, results of pairwise comparisons ($\alpha = 0.05$) of captures of wild *Ceratitis capitata* among the four food baits over all trapping periods and for the individual trapping periods based on the Wilcoxon rank sum test. Numerical averages and SE are presented in Figure 2.

		Week							
Food bait	**All**	**1**	**2**	**3**	**4**	**6**	**7**	**8**	**9**
Torula yeast borax	A	A [4]	A [4]	A [4]	A [4]	A [4]	A [4]	A [4]	A [4]
Food cone	B	AB [2]	B [1]	B [1]	B [1]	B [1]	B [1]	B [2]	B [1]
1-1-1 vial-lure	C	AB [3]	AB [2]	AB [3]	AB [3]	B [2]	AB [2]	AB [3]	AB [3]
Unipak	BC	B [1]	AB [3]	B [2]	B [2]	B [3]	AB [3]	B [1]	B [2]

For a given column, food baits sharing a letter were not significantly different. Weeks 5 and 10 were omitted, as bait had no significant effect in these weeks. Bracketed numbers represent rank order of average captures per trap for a given interval, where 1 is highest and 4 is lowest.

Table 5: For Guatemala in 2024, results of pairwise comparisons ($\alpha = 0.05$) of captures of wild *Ceratitis capitata* among the four food baits over all trapping periods and for the individual trapping periods based on the Wilcoxon rank sum test. Numerical averages and SE are presented in Figure 3.

	Week						
Food bait	**All**	**5**	**6**	**7**	**8**	**9**	**10**
Food cone	A	B [4]	B [4]	B [3]	B [4]	B [4]	B [4]
1-1-1 vial-lure	BC	AB [2]	A [2]	AB [2]	AB [2]	AB [2]	A [2]
Unipak	C	A [1]	A [1]	A [1]	A [1]	A [1]	A [1]
CT	AB	AB [3]	A [3]	B [4]	AB [3]	AB [3]	AB [3]

For a given column, food baits sharing a letter were not significantly different. Weeks 1–4 were omitted, as no significant pairwise differences were detected in these weeks. Bracketed numbers represent rank order of average captures per trap for a given interval, where 1 is highest and 4 is lowest.

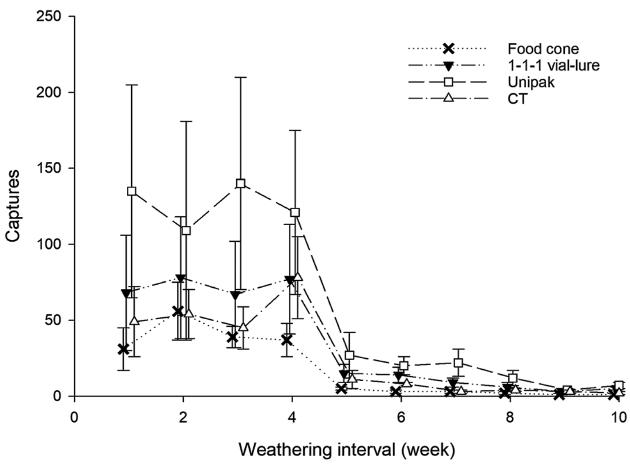

Figure 3: In Guatemala in 2024, captures of wild Mediterranean fruit fly, *Ceratitis capitata*, in Multilure traps baited with four food baits at varying weathering intervals of the dry synthetic baits. Symbols represent mean weekly captures (±1 SE; sexes combined) for individual traps ($N = 5$ per bait type per period).

differences between individual treatments were detected only in weeks 5–10 (Table 5). During each of these weeks, captures of *C. capitata* in Unipak-baited traps were significantly greater than captures in food cone- or CT-baited traps. Captures in traps baited with 1-1-1 vial-lures or CTs had intermediate numbers of captures, which often did not differ significantly from the Unipaks or the food cones.

3.3 Hawaii

3.3.1 Mediterranean fruit fly

For the Mediterranean fruit fly, based on data pooled over all trapping periods, mean female percentages were 78 % for TYB ($N = 46$ traps), 69 % for food cones ($N = 11$ traps), 73 % for Difusors ($N = 23$ traps), 74 % for 1-1-1 vial-lures ($N = 16$ traps), and 70 % for 3-in-1 vial-lures ($N = 18$ traps). The variation in female percentages among treatments was not significant ($H = 7.1$, $df = 4$, $P = 0.13$). Female percentages in Hawaii were substantially greater than those observed in Guatemala.

Analysis of the entire data set showed that both week ($\chi^2 = 3{,}447.4$, $df = 4$, $P < 0.001$) and bait ($\chi^2 = 1{,}247.6$, $df = 4$, $P < 0.001$) had significant effects on captures of *C. capitata* (Figure 4). The week by bait interaction term was also significant ($\chi^2 = 1{,}169.1$, $df = 16$, $P < 0.001$). Based on the complete data set, pairwise comparisons showed that captures of *C. capitata* in TYB-baited traps were significantly greater than any other treatment and that captures in food cone-baited traps were significantly lower than any other treatment (Table 6). Difusors attracted significantly more medflies than the 1-1-1 vial-lures but similar numbers as the 3-in-1 vial-lures. Captures did not differ significantly between the two types of vial-lures.

For all weathering intervals, bait type was found to have a significant effect on the numbers of captures (Table 6). At week 0, medfly captures were similar in TYB-, food cone-, Difusor-, and 1-1-1 vial-lure-baited traps, and captures for these food

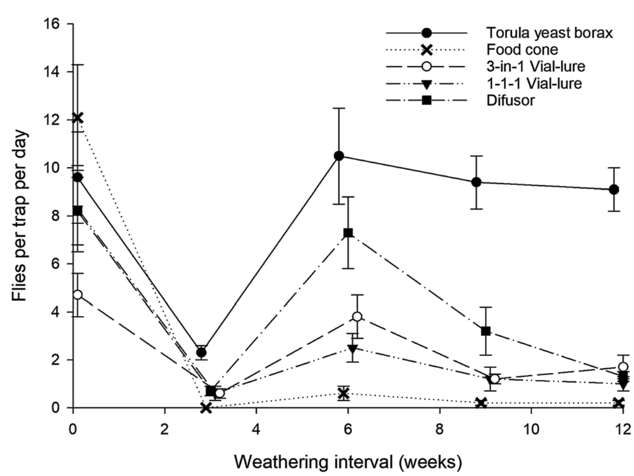

Figure 4: In Hawaii in 2023, captures of wild Mediterranean fruit fly, *Ceratitis capitata*, in Multilure traps baited with five different food baits at varying weathering intervals of the dry synthetic baits (torula yeast borax was fresh for each trapping interval). Symbols represent mean daily captures (±1 SE; sexes combined) for individual traps operated for 4–6 days per trapping period ($N = 10$ per bait type per period).

Table 6: For Hawaii in 2023, results of pairwise comparisons ($\alpha = 0.05$) of captures of wild *Ceratitis capitata* among the five food baits over all trapping periods and for the individual trapping periods based on the Wilcoxon rank sum test. Numerical averages and SE are presented in Figure 4.

	Week					
Food bait	**All**	**0**	**3**	**6**	**9**	**12**
Torula yeast borax	A	A [2]	A [1]	A [1]	A [1]	A [1]
Food cone	B	A [1]	B [5]	B [5]	B [5]	B [5]
3-in-1 vial-lure	CD	B [5]	C [4]	C [3]	BC [3]	C [2]
1-1-1 vial-lure	C	AB [4]	C [3]	BC [4]	B [4]	BC [4]
Difusor	D	A [3]	C [2]	A [2]	C [2]	C [3]

For a given column, food baits sharing a letter were not significantly different. Bracketed numbers represent rank order of average captures per trap for a given interval, where 1 is highest and 4 is lowest.

baits, except for the 1-1-1 vial-lure, were significantly greater than those for 3-in-1 vial-lures. From weeks 3 to 12, however, TYB attracted significantly greater numbers of medflies than any other food bait, except for week 6 when TYB- and Difusor-baited traps captured similar numbers of medflies. Difusor-baited traps captured significantly more medflies than food cone-baited traps in all trapping periods between weeks 3 and 12. Over this span, Difusors also attracted equivalent or greater numbers of medflies than either type of vial-lure. After week 0, the 3-in-1 vial-lures generally outperformed the food cones, while the 1-1-1 lure-vials did not. The two types of vial-lures did not differ from one another in any trapping interval. As these findings suggest, aside from week 0, food cones attracted statistically equivalent or significantly fewer medflies than any of the other food baits.

3.3.2 Oriental fruit fly

For the oriental fruit fly, based on data pooled over all trapping periods, mean female percentages were 79 % for TYB ($N = 47$ traps), 76 % for food cones ($N = 16$ traps), 78 % for Difusors ($N = 24$ traps), 76 % for 1-1-1 vial-lures ($N = 26$ traps), and 81 % for 3-in-1 vial-lures ($N = 18$ traps). The variation in female percentages among treatments was not significant ($H = 3.8$, $df = 4$, $P = 0.43$).

Based on the entire data set, both week ($\chi^2 = 395.3$, $df = 4$, $P < 0.001$) and bait ($\chi^2 = 1{,}516.5$, $df = 4$, $P < 0.001$) had significant effects on captures of *B. dorsalis* (Figure 5). The interaction term was also significant ($\chi^2 = 272.1$, $df = 16$, $P < 0.001$). Based on data from all trapping periods, pairwise comparisons showed that captures of *B. dorsalis* in TYB-baited traps were significantly greater than any other treatment, while there were no significant differences among the other food baits (Table 7).

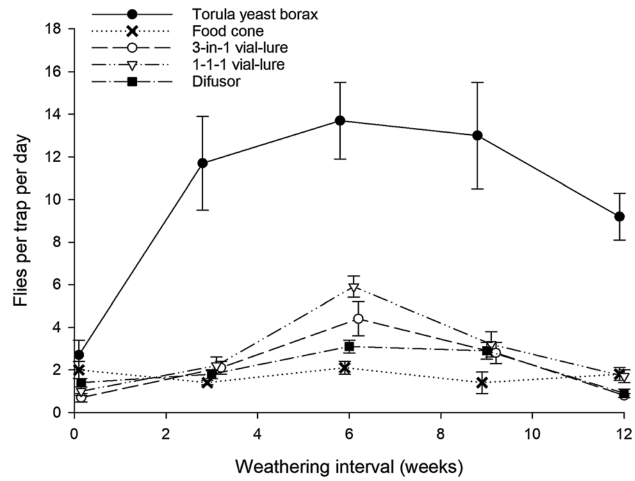

Figure 5: In Hawaii in 2023, captures of wild oriental fruit fly, *Bactrocera dorsalis*, in Multilure traps baited with five different food baits at varying weathering intervals of the dry synthetic baits (torula yeast borax was fresh for each trapping interval). Symbols represent mean daily captures (±1 SE; sexes combined) for individual traps operated for 4–6 days per trapping period ($N = 10$ per bait type per period).

Table 7: For Hawaii in 2023, results of pairwise comparisons ($\alpha = 0.05$) of captures of wild *Bactrocera dorsalis* among the five food baits over all trapping periods and for the individual trapping periods based on the Wilcoxon rank sum test. Numerical averages and SE are presented in Figure 5.

	Week					
Food bait	**All**	**0**	**3**	**6**	**9**	**12**
Torula yeast borax	A	A [1]	A [1]	A [1]	A [1]	A [1]
Food cone	B	A [2]	B [5]	B [5]	B [5]	B [2]
3-in-1 vial-lure	B	C [5]	B [3]	CD [3]	C [4]	C [5]
1-1-1 vial-lure	B	BC [4]	B [2]	D [2]	C [2]	BC [3]
Difusor	B	AB [3]	B [4]	C [4]	C [3]	BC [4]

For a given column, food baits sharing a letter were not significantly different. Bracketed numbers represent rank order of average captures per trap for a given interval, where 1 is highest and 4 is lowest.

Bait type was found to have a significant effect on the numbers of captures for all weathering intervals (Table 7). At week 0, oriental fruit fly captures were similar in TYB-, food cone-, and Difusor-baited traps, while captures with the vial-lures were significantly lower. At week 3, TYB outperformed all other baits, which did not differ among themselves. From week 6 to 12, TYB again attracted significantly more *B. dorsalis* than any other bait, food cones generally attracted significantly fewer *B. dorsalis* than any other bait, and Difusors and the vial-lures appeared to have similar attractiveness.

4 Discussion

This study was undertaken to provide additional data on the performance of vial-lures relative to TYB as well as other dry synthetic food baits in capturing Mediterranean fruit flies. We focused on comparisons between the vial-lures and TYB given the recent findings of Enkerlin et al. (2025) showing that, consistently over study sites in five countries, 3-in-1 lure-vials attracted similar or greater numbers of *C. capitata* than TYB over 8-week sampling periods during which TYB was replaced weekly while the vial-lures were never replaced. Large-scale trapping programs would benefit substantially from such long-lasting lures, as costs associated with trap supplies and servicing would be much reduced.

The performance of vial-lures relative to TYB varied among the study locations. Data from Florida were similar to those presented by Enkerlin et al. (2025), i.e., the vial-lure formulations performed as well or better than TYB up to 10 weeks. Based on analysis for the entire study period, there was no evidence that bait type had a significant effect on captures of released, male medflies, meaning – broadly – that the baits tested were equivalent. However, this analysis using data from the entire trapping period does not examine possible variation in the effective longevity of the different baits. Accordingly, analyses of individual trapping periods showed that, for Florida, captures of *C. capitata* in vial-lure-baited traps were similar to or greater than captures in TYB-baited traps for all trapping periods.

In Guatemala in 2017, traps baited with 1-1-1 vial-lures (3-in-1 vial-lures were not tested) captured significantly more wild individuals (Table 3) and released, sterile males (Table 4) of *C. capitata* than TYB-baited traps when the entire trapping period was analyzed. For wild males, weekly analyses detected no differences between these two baits (except for week 6, Table 3), whereas the 1-1-1 vial-lures attracted significantly more sterile males than TYB in each week (Table 4).

In Hawaii, the relative performance of TYB and the vial-lures was opposite that observed in Florida or Guatemala. That is, in Hawaii, TYB attracted significantly greater numbers of wild *C. capitata* than 1-1-1 or 3-in-1 vial-lures based on data from the entire study period as well as from individual trapping intervals. Interestingly, consistent with prior studies (Leblanc et al. 2010; Miranda et al. 2001), a strong female bias was observed for *C. capitata* captures for all food baits in Hawaii, whereas in Guatemala female constituted only 23 % and 47 % of captures in 2017 and 2024, respectively. Reasons for the male bias in Guatemala are unknown.

To summarize, for *C. capitata* the vial-lure baits were, in general, equal or superior to TYB in Florida and Guatemala (2017) but were inferior to TYB in Hawaii. The result for Hawaii was unexpected, because data from the same site (collected in 2018) were included in Enkerlin et al. (2025) and revealed that both 1-1-1 and 3-in-1 lure-vials attracted similar numbers of medflies as TYB. Reasons for these incongruent results are not known, as (i) the production process and composition of both TYB pellets and vial-lures were unchanged between 2018 and 2023 (A. Ramsey and R. Alvarado, personal communication), (ii) the trapping protocol was likewise similar between these years, and (iii) trapping was conducted at the same time of the year (2018: October–December; 2023: September–November) under similar weather conditions.

Regarding the effectiveness of 3-in-1 and 1-1-1 vial-lure formulations, there was no marked difference in their performance relative to TYB. In Florida, captures of released *C. capitata* males in 3-in-1 or 1-1-1 vial-lure-baited traps were similar to TYB-baited traps for all intervals aside from week 6 when 1-1-1 vial-lures attracted significantly more flies than 3-in-1 vial-lures or TYB. In Hawaii, wild medfly captures were similar for 3-in-1 or 1-1-1 vial-lure-baited traps for all intervals. Given these findings, the 3-in-1 vial-lures appear preferable, as the production cost of combination units is less than that of separate 1-1-1 vial-lures (R. Alvarado, personal communication), and inserting or removing a single dispenser requires less handling time than multiple dispensers.

Regarding the other food baits examined, food cones were included in all tests, because, as noted previously, they are currently used in detection programs in Florida and Texas, and thus their performance is of great practical value. Like the vial-lures, the performance of food cones varied with location. For example, in Hawaii food cone-baited traps captured significantly fewer *C. capitata* than TYB-baited traps in all intervals (excepting week 0) and often had significantly smaller catch than vial-lure-baited traps. This finding is consistent with previous research conducted in Hawaii (Shelly et al. 2020, 2023). In contrast, in Guatemala in 2017 traps with food cones captured significantly more wild and released medflies than TYB-baited traps for both the full trapping period and individual weeks. In 2017, captures with food cones were similar to those observed with 1-1-1 vial-lures and Unipaks for both wild and released flies. In Guatemala in 2024, Unipak-baited traps captured significantly more medflies than food cone-baited traps, but food cones generally attracted as many medflies as 1-1-1 vial-lures or CTs. In Florida, *C. capitata* captures with food cones varied greatly over time, having the highest average catch in week 2 but the lowest average catch from weeks 4–8. This trend of high, initial attractiveness of food cones followed by a rapid decline in potency mirrors results from Hawaii (present study; Shelly et al. 2020, 2023).

Although the data were variable, the results presented here suggest that food cones are generally less attractive to *C. capitata* than vial-lures. During all trapping periods (aside from Guatemala in 2017), average captures in food cone-baited traps were often lower than those in vial-lure-baited traps, and in many cases these differences were statistically significant.

Three other food-based attractants were included in this study, but each of these was tested in only one location, rendering their assessment preliminary. The Difusor has been tested previously in Spain (Navarro-Llopis et al. 2008), Uruguay (Delgado et al. 2022), and Hawaii (Shelly and Fezza 2024). In contrast to the present study, the Difusor has generally attracted similar or greater numbers of *C. capitata* than TYB, and this product merits further testing. The Unipak has been tested previously with *C. capitata* in Hawaii and Florida, and the results have been inconsistent (Jang et al. 2007). In the present study, Unipaks attracted significantly more *C. capitata* than TYB (Guatemala in 2017), while Shelly and Fezza (2024), working in Hawaii, found that Unipaks attracted significantly fewer *C. capitata* than TYB. Jang et al. (2007) observed that captures of released male medflies in Florida were similar between Unipak- (termed Suterra PTA) and TYB-baited traps. Finally, to our knowledge, the present study includes the first published data on the ChemTica food bait, consequently a more complete evaluation awaits additional testing.

In addition to *C. capitata*, *B. dorsalis* was captured in Hawaii in numbers sufficient for statistical analysis. The results presented here are consistent with earlier studies, i.e., TYB-baited traps generally attracted significantly more *B. dorsalis* than food cones, Unipaks, or Difusors (Shelly and Fezza 2024; Shelly et al. 2020, 2022, 2023). Similarly, Enkerlin et al. (2025) reported that TYB attracted more *B. dorsalis* than 3-in-1 vial-lures.

In conclusion, neither the present study nor the collective findings of prior research identify a particular dry, synthetic food-based attractant that is uniformly and maximally attractive to *C. capitata*. The data available do clearly discriminate among these food attractants as the most effective replacement for TYB. Thus, the choice of a suitable alternative may depend primarily upon its performance under local environmental conditions as well as its local availability and cost. Regardless of the specific bait used, however, the extended field longevity will likely eliminate the high servicing costs associated with TYB-baited traps.

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Author contributions: TS data collection in Hawaii, statistical analysis, manuscript preparation; PD, TS & KF data collection in Florida; JM experimental design, data collection in Florida, manuscript preparation; GK data collection in Florida; PR data collection in Guatemala, manuscript preparation; SW & DK develop vial-lures, manuscript preparation; CB project administration, manuscript preparation. The findings and conclusions in this publication are those of the authors and should not be construed to represent any official USDA or U.S. Government determination or policy.
Use of Large Language Models, AI and Machine Learning Tools: None used in this study.
Conflict of interest: None declared.
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Data availability: The raw data can be obtained from the corresponding author upon request.

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