Captures of Oriental Fruit Flies and Melon Flies (Diptera: Tephritidae) in Traps Baited With Torula Yeast Borax Solution Or 2- Or 3-Component Synthetic Food Cones in Hawaii

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Captures of oriental fruit flies and melon flies (Diptera: Tephritidae) in traps baited with torula yeast borax solution or 2- or 3-component synthetic food cones in Hawaii

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Abstract

Food-based traps are an integral component of detection systems for invasive fruit fly (Diptera: Tephritidae) species which pose a serious threat to many agricultural crops. A commonly used bait is torula yeast borax solution; however, it is attractive for relatively short intervals (1–2 wk), necessitating frequent bait replacement. A dry, synthetic food bait that incorporates several components into a single matrix (or food cone) has been developed and appears to be effective for as long as 4 to 10 wk in field trials with the Mediterranean fruit fly (*Ceratitis capitata* [Wiedemann]) and the Caribbean fruit fly (*Anastrepha suspensa* [Loew]) (both Diptera: Tephritidae). Based on these results, food cones are used now in several large-scale fruit fly detection programs even though their attractiveness to other economically important tephritids, most notably *Bactrocera* and *Zeugodacus* species, has not been well studied. The goal of this study was to compare the captures of oriental fruit fly (*Bactrocera dorsalis* [Hendel]) and melon fly (*Zeugodacus cucurbitae* [Coquillett]) (both Diptera: Tephritidae) in traps baited with torula yeast borax solution with captures in traps baited with 3-component (ammonium acetate, putrescine, and trimethylamine) or 2-component (ammonium acetate and putrescine) food cones. Data from wild and released flies of both species showed that captures were significantly higher in traps baited with the torula yeast borax than those with either type of synthetic formulation. Implications of this finding for trapping programs are discussed.

Key Words: invasive fruit flies; detection; food baits; *Bactrocera*; *Zeugodacus*

Resumen

Las trampas alimentarias son un componente integral para los sistemas de detección de especies invasoras de moscas de la fruta (Diptera: Tephritidae) que representan una seria amenaza para muchos cultivos agrícolas. Un cebo comúnmente utilizado es la solución de bórax de levadura de torula; sin embargo, es atractivo de intervalos relativamente cortos (1 a 2 semanas), lo que requiere un reemplazo frecuente del cebo. Se ha desarrollado un cebo alimenticio sintético seco que incorpora varios componentes en una sola matriz (o cono alimenticio) y parece ser eficaz durante 4 a 10 semanas en ensayos de campo para la mosca mediterránea de la fruta (*Ceratitis capitata* [Wiedemann]) y la mosca de la fruta del Caribe (*Anastrepha suspensa* [Loew]) (Diptera: Tephritidae). Según estos resultados, los conos alimentarios se utilizan ahora en varios programas de detección de moscas de la fruta a gran escala, aunque su atractivo para otros tefrítidos de importancia económica, sobre todo las especies de *Bactrocera* y *Zeugodacus*, no ha sido bien estudiado. El objetivo de este estudio fue comparar las capturas de mosca oriental de la fruta (*Bactrocera dorsalis* [Hendel]) y mosca del melón (*Zeugodacus cucurbitae* [Coquillett]) (Diptera: Tephritidae) en trampas cebadas con solución de bórax de levadura de torula con capturas en trampas cebadas con conos alimentarios de 3 componentes (acetato de amonio, putrescina y trimetilamina) o de 2 componentes (acetato de amonio y putrescina). Los datos de moscas silvestres y liberadas de ambas especies mostraron que las capturas fueron significativamente más altas en trampas cebadas con bórax de levadura de torula que en aquellas con cualquier tipo de formulación sintética. Se discuten las implicaciones de este hallazgo para los programas de captura.

Palabras Clave: moscas invasoras de la fruta; detección; cebos alimenticios; *Bactrocera*; *Zeugodacus*

Detection of invasive fruit flies (Diptera: Tephritidae) depends heavily on traps baited with male lures, which are natural or synthetic compounds that are highly attractive to males of many important pest species (Tan et al. 2014). While quite potent, male lures suffer limitations because (as the name implies) they are sex-specific, and males of many tephritid species, including some of economic importance, do not respond to the lures currently in use (Drew & Hooper 1981; Royer 2015). As a result, fruit fly detection programs also include food-baited traps that, although less attractive than male lures, are general attractants to both sexes of many tephritid species (Epsky et al. 2014).

By the mid-1990s, an aqueous solution of torula yeast borax (with borax added to reduce composition of the bait and the captured insects, López et al. 1971) was adopted as the standard food attractant for tephritid trapping systems worldwide (Heath et al. 1995). Nonetheless, this food bait is problematic, primarily because it is attractive for only a relatively short time interval, with replacement required every 1 to 2 wk (FAO/IAEA 2018). As a result, the use of dry synthetic food baits was investigated and initially involved placement within traps of 3 separate packets that contained ammonium acetate, putrescine, and trimethylamine, respectively (Heath et al. 1997). Field tests of this

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synthetic bait, commercially available as BioLure (Suterra LLC, Bend, Oregon, USA), focused largely on the Mediterranean fruit fly, *Ceratitis capitata* (Wiedemann), as well as the Caribbean fruit fly, *Anastrepha suspensa* (Loew), and Mexican fruit fly, *Anastrepha ludens* (Loew) (all Diptera: Tephritidae), with the caveat that, for the *Anastrepha* species, a 2-component bait (ammonium acetate and putrescine only) was more attractive than the full 3-component lure (Holler et al. 2006). In general, the synthetic food baits were found to be equally or more attractive than torula yeast borax slurry and to remain attractive for 4 to 10 wk in the field (Heath et al. 1997; Katsoyannos et al. 1999; Thomas et al. 2001; Epsky et al. 2011).

Eventually, to ease handling in the field, a solid, polymeric 'food cone' dispenser (Scentry Biologicals Inc., Billings, Montana, USA) was developed that contains all 3 components (or 2 components for *Anastrepha*), thereby eliminating the need to place multiple packets inside traps. As with BioLure, field testing of food cones targeted *C. capitata* and *A. suspensa*, but to our knowledge this testing has been limited to a single study. Jang et al. (2007) performed a series of field tests on food cones, and although some of these tests used sterile flies exclusively or failed to include torula yeast borax-baited traps for comparison, their results indicated that food cones were attractive to *C. capitata* and *A. suspensa* for intervals lasting 6 to 10 wk. Based largely on these studies, food cones have been adopted by several large-scale detection programs in the USA (i.e., Florida and Texas).

Comparatively little work has been conducted on the attractiveness of synthetic, dry food baits of any formulation to *Bactrocera* species. Instead, most research on food attractants for this genus has compared the attractiveness of different types of protein hydrolysate solutions derived from different yeasts, corn, or soybean (Fabre et al. 2003; Duyck et al. 2004; Vargas & Prokopy 2006; Ekesi et al. 2014; Biasazin et al. 2018; Vitanović et al. 2020), or has investigated other organic baits such as fishmeal, beef, bread, beer waste, or fruits (Satpathy & Samarjit 2002; Bharathi et al. 2004; Piñero et al. 2017; Ugwu 2019). This emphasis most likely reflects the high cost or unavailability of synthetic food baits in many parts of the world (Aluja & Piñero 2004). Two studies that have compared synthetic food baits to torula yeast borax solution indicate that the yeast solution is significantly more attractive to *Bactrocera* species. Working in Hawaii and with the 3 compounds presented in separate packets within a trap, Leblanc et al. (2010) found that, for both the oriental fruit fly, *Bactrocera dorsalis* (Hendel) (Diptera: Tephritidae), and the melon fly, *Zeugodacus cucurbitae* (Coquillett) (Diptera: Tephritidae) (which, until recently, was placed in the genus *Bactrocera*, Virgilio et al. 2015), significantly more individuals of both sexes were captured in the torula yeast borax-baited traps than those baited with the synthetic food packets, with the exception that captures of *B. dorsalis* males were similar for the 2 food baits. More recently, Shelly et al. (2020) compared captures of *B. dorsalis* in traps containing torula yeast borax or the 3-component food cone and reported the same trends described by Leblanc et al. (2010), i.e., female numbers in the yeast-baited traps generally were greater than those found in food cone-baited traps, whereas male captures were similar between the 2 food lures. Because the catch was markedly female-biased in traps with torula yeast borax, the total catch was greater significantly in these traps than those with food cones.

The present study describes 2 experiments that provide additional information on the attraction of *B. dorsalis* and *Z. cucurbitae* to food baits. First, captures of wild flies were compared among traps baited with torula yeast borax solution or 2- or 3-component food cones. Second, captures of these species were compared among the same 3 food types in release-recapture trials conducted in a fruit orchard. As shown, the 2 data sets were generally in agreement, and the implications of these results for fruit fly detection programs are discussed.

Materials and Methods

TRAPPING WILD FLIES

Study Sites

Trapping of wild *B. dorsalis* was conducted on Hawaii Island (the "Big Island") at the edge of second-growth forest (170 masl) approximately 10 km south of Hilo, Hawaii, USA. Strawberry guava (*Psidium cattleyanum* L.; Myrtaceae), a preferred host of *B. dorsalis* (Vargas et al. 1990), was abundant in the forest. Trapping was performed during Jan-Feb 2021, during which daily maximum and minimum air temperatures averaged 23.7 °C and 16.2 °C, respectively (NOAA weather station, Keaau, Hawaii, USA).

Trapping of wild *Z. cucurbitae* was conducted on Oahu in an abandoned citrus grove approximately 5 km northeast of Kapolei, Hawaii, USA. The grove was adjacent to commercial fields of tomato (*Solanum lycopersicum* L.; Solanaceae), a host plant of *Z. cucurbitae*, ivy gourd (*Coccinia grandis* (L.) Voight; Cucurbitaceae), and bitter melon (*Momordica charantia* L.; Cucurbitaceae); invasive weeds and host plants also were abundant in the citrus grove. Trapping was performed during Jan to Feb 2021, during which daily maximum and minimum air temperatures averaged 27.7 °C and 20.6 °C, respectively (National Weather Service, Honolulu International Airport, Honolulu, Hawaii, USA).

Traps and Baits

The 3 food baits used in this study were deployed in Multilure traps (Better World Manufacturing Inc., Fresno, California, USA), which are 2-piece, plastic MacPhail-like traps (FAO/IAEA 2018). The top portion is clear, and the bottom is bright yellow and holds liquid food bait or an aqueous preservative. Flies enter the bottom of the trap via an open-ended invagination and fall into the liquid reservoir, which serves as the killing mechanism. A wire hanger at the top of the trap is used to suspend the trap from tree branches.

The torula yeast borax solution was prepared 1 d before field deployment by adding 1 torula yeast borax pellet (Scentry Biologicals Inc., Billings, Montana, USA) per 100 mL of a water and antifreeze solution (90% and 10%, respectively; SPLASH RV & Marine Antifreeze [14% propylene glycol], SPLASH Products Inc., St. Paul, Minnesota, USA). Antifreeze is added routinely to the torula yeast borax bait in order to reduce evaporation and decay of captured insects (FAO/IAEA 2018). For traps containing this liquid food, we placed 300 mL of the torula yeast borax slurry per trap.

For the remaining traps, a single 2- or 3-component food cone was placed in a capped, slatted well built into the top of the Multilure trap, i.e., the associated odor was emitted from the invaginated opening in the bottom of the trap. For food cone-baited traps, we placed 300 mL of the water/antifreeze solution (90:10 volumetric proportions as above but prepared without the torula yeast pellets) in the trap. Unlike the torula yeast borax, which was prepared fresh for each sampling period, the food cones were fresh for the initial sampling period but then aged for use in subsequent sampling periods. To weather the food cones, Multilure traps containing food cones (but no liquid in the bottom of the trap) were hung about 2 m above ground in covered outdoor areas adjacent to USDA (Hawaii, USA) laboratories under similar environmental conditions as the trapping sites.

Trapping Protocol

At the Big Island site, where data on *B. dorsalis* were gathered, traps were deployed at 2 wk intervals from 0 to 6 wk. During each trapping bout, 12 traps were deployed per treatment (36 total traps). Traps were placed 1.5 to 2 m aboveground in shaded locations at the forest edge. Treatments were positioned in repeated sequences (e.g., torula yeast borax/2-component food cone/3-component food cone) with neighboring traps separated by 20 to 30 m. The same transect was used over all 4 sampling periods, with the treatment alternated at a particular site among sampling periods. Traps operated for 2 d per sampling interval. When a trap was collected, the liquid was poured through a sieve to retain the catch, and samples were returned to the laboratory to identify and count the flies.

The same basic protocol was followed in trapping *Z. cucurbitae* on Oahu, with a few exceptions. First, 10 traps were deployed per treatment during each sampling interval (30 total traps). In addition, traps were placed in 2 rows of trees, with rows separated by 20 m and traps within the same row separated by 5 to 10 m. The limited area available for trapping prompted the small distance between adjacent traps, but because food-based traps appear to have low attractiveness to *Z. cucurbitae* (Shelly & Manoukis 2018) interference between traps was likely negligible.

RELEASE AND RECAPTURE EXPERIMENT

A release-recapture experiment was conducted on Oahu to compare captures in traps baited with torula yeast borax solution or 2- or 3-component food cones. Because spatial patchiness of wild populations may affect trapping data, the release-recapture experiment was undertaken to guarantee that the different food baits were available equally to the flies. This experiment was conducted at the same site and using the same general protocol as described in Shelly et al. (2020). Additionally, the same methods of insect rearing and colony maintenance were used in the present study. Accordingly, this information is presented in abbreviated fashion here, and readers are referred to that earlier study for additional details.

Study Site

This experiment was conducted in a small citrus orchard at the University of Hawaii's Urban Garden, Pearl City, Oahu, Hawaii, USA. The orchard contains 55 trees arranged in 9 rows with 5 to 7 trees per row. A few scattered fruits were present, but most trees bore no fruit during the study. Releases were conducted in Mar and Apr 2021, when daily maximum and minimum temperatures averaged 27.1 °C and 20.6 °C, respectively (National Weather Service, Honolulu International Airport, Honolulu, Hawaii, USA).

Insects

Releases included both *B. dorsalis* and *Z. cucurbitae* and involved adults derived from laboratory colonies started with wild flies reared from field-collected hosts. For *B. dorsalis*, the colony was started with 500 to 700 adults reared from common guava (*P. guajava*) collected on Oahu, and adults used in the experiment were 9 to 10 generations removed from the wild. For *Z. cucurbitae*, the colony was started with 400 to 500 adults reared from zucchini (*Cucurbita pepo* L.; Cucurbitaceae) collected on Oahu, and adults used in this study were 1 generation removed from the wild. Released flies were virgins and 7 to 11 d old, i.e., still immature, because sexual maturity is attained at 14 to 18 d of age (Shelly, unpublished data). Adults were fed a mixture of sugar and yeast hydrolysate until 1 d before release, when food was removed to stimulate food searching behavior after release.

For both species, 250 individuals of each sex were released per replicate. Preliminary trapping with male lures (cue-lure and methyl eugenol, respectively) indicated that the study site contained few individuals of *Z. cucurbitae* (presumably owing to the lack of suitable hosts) but larger numbers of *B. dorsalis*. Consequently, released *Z. cucurbitae* were not marked, but released *B. dorsalis* were marked by placing a small dot of enamel paint on the dorsum of the thorax (flies were chilled and thus immobilized for marking). Marking took place 1 to 3 d before release.

Release and Recapture Protocol

Captures of released flies were compared among Multilure traps baited with torula yeast borax solution or 2- or 3-component food cones. The food baits were prepared in the same manner described above. In this experiment, all food baits were fresh, i.e., food cones were not weathered. Six replicates were performed at approximately weekly intervals.

Flies were released in a tree located near the center of the orchard at 9:00 AM by holding cages in the canopy, removing a glass side of the cage, and gently tapping the cage to prompt flight. Traps, which were deployed just before fly release, were placed on 12 trees evenly spaced in a rough circle (radius 10–14 m) about the release tree, and 2 traps were placed on each of these trees (separated by 1.5–2 m). Thus, 24 traps were deployed per release, with 8 traps per food bait. Traps on the same tree contained different food baits, i.e., pairs of baits included torula yeast borax and 2-component food cones, torula yeast borax and 3-component food cones, or 2- and 3-component food cones. Each pairing occurred on 4 different trees, with the 3 pair types arranged in repeating sequences around the circle. This sequential pattern was used for each release, and pairings were rotated 1 tree between successive replicates so that specific pairings were not always placed on a particular tree. Traps operated for 24 h after a release, and samples were collected and processed in the manner described above.

STATISTICAL ANALYSIS

Numbers of captured wild flies were analyzed using general linearized models, with bait and wk as independent variables. For *B. dorsalis*, the raw data were distributed normally; consequently a model was constructed using the Gaussian normal distribution and the identity link. For *Z. cucurbitae*, data were non-normal, and a Poisson distribution was chosen with the log link. Sex ratio (female proportion of total catch) also was analyzed for both species using the same, respective distributions and link functions. However, to ensure that sex ratio computation was based on adequate sample sizes, sex ratios were determined only for those traps that captured a minimum of 10 flies. In all tests, the significance of the independent variables was tested using a likelihood ratio chi-square, with $df = 3$ for wk and $df = 2$ for bait. The post-hoc Tukey's test was used to identify significant differences in pairwise comparisons. General linearized models were performed with JMP 14 software (SAS Institute, Cary, North Carolina, USA).

Regarding the release-recapture experiment, numbers of captured released flies were analyzed using general linearized models with bait and replicate as independent variables. As the raw data were non-normal for both species, data were log (× + 1) transformed and analyzed with a Poisson distribution with the log link. Tests of significance (where $df = 5$ for replicate and $df = 2$ for bait) and the software used were the same as those given above. Because captures were relatively low in this experiment, sex ratios were analyzed, not on a per trap basis (as for the wild flies), but using an aggregate sex ratio (female proportion of total catch) based on counts pooled over all traps of a given food bait for a given replicate. This approach yielded 6 sex ratios per food bait (i.e., 1 ratio per food bait per replicate) which were then compared with a 1-way ANOVA (arc sine transformed data met the parametric assumptions of normality and homoscedasticity). The Tukey's test was used to identify significant differences in pairwise comparisons. Analysis of sex ratio was completed with SigmaPlot 11 (Systat Software, San Jose, California, USA).

Results

TRAPPING WILD FLIES

Data regarding captures of *B. dorsalis* are presented in Fig. 1. For this species, both wk and bait had significant effects on captures of both females (wk: $\chi^2 = 18.2$; $P = 0.0004$; bait: $\chi^2 = 75.9$; $P < 0.0001$) and males (wk: $\chi^2 = 7.9$; $P = 0.047$; bait: $\chi^2 = 11.9$; $P = 0.003$). Temporal variation presumably reflected both natural population dynamics as well as possible differences in environmental conditions during sampling (e.g., wind speed and direction). More interestingly, the sexes differed in their attraction to the different baits. Significantly greater numbers of *B. dorsalis* females were captured in traps baited with torula yeast borax solution than either the 2- or 3-component food cones ($P < 0.0001$ in both cases), whereas there was no difference in female captures between the 2 types of food cones ($P = 0.97$). In contrast, significantly greater numbers of *B. dorsalis* males were captured in traps baited with 2- or 3-component food cones than the torula yeast borax solution ($P = 0.005$ and $P = 0.03$, respectively), whereas there was no difference in male captures between the 2 types of food cones ($P = 0.79$).

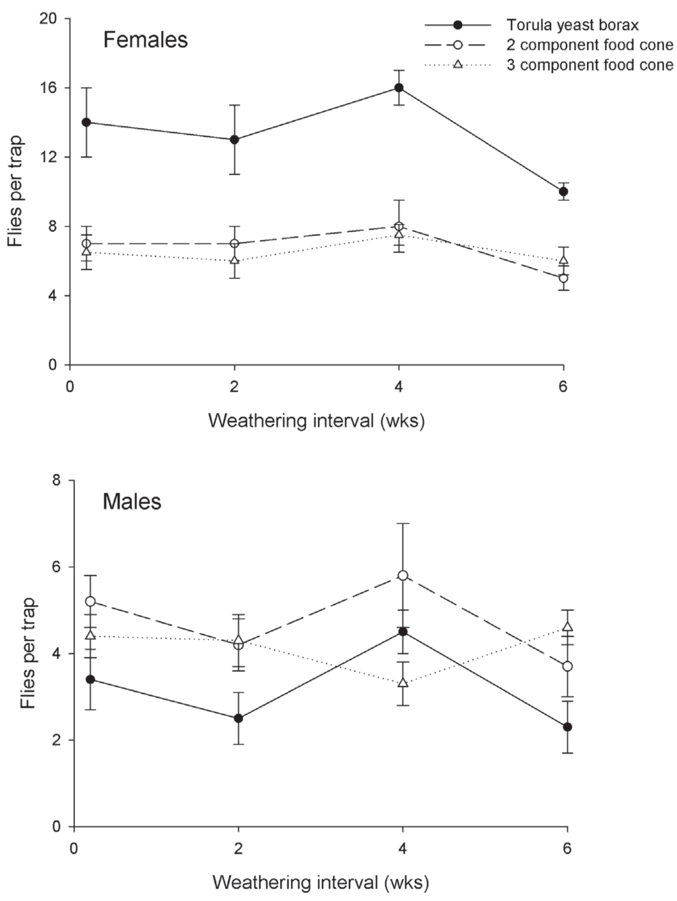


Fig. 1. Captures of wild *Bactrocera dorsalis* in traps baited with torula yeast borax solution, 2-component cones, or 3-component cones. Symbols represent means (± 1 SE); $N = 12$ traps per treatment per weathering interval.

As these results suggest, sex ratio of *B. dorsalis* varied significantly among the baits ($\chi^2 = 71.9$; $P < 0.001$). On average, females represented 80.9% of total captures in traps baited with torula yeast borax ($N = 41$) compared to only 58.3% and 60.2% of traps with 2- or 3-component food cones, respectively ($N = 29$ and 31, respectively; for all baits, only traps with ≥ 10 flies were considered). Sex ratio differed significantly between traps baited with torula yeast or 2- or 3-component food cones ($P < 0.001$ in both cases) but did not differ significantly between 2- or 3-component food cones ($P = 0.77$). Sex ratio of captured *B. dorsalis* did not vary significantly with wk ($\chi^2 = 1.0$; $P = 0.79$).

Data regarding captures of wild *Z. cucurbitae* are presented in Fig. 2. Both wk and bait had significant effects on captures of both females (wk: $\chi^2 = 1087.3$; $P < 0.0001$; bait: $\chi^2 = 1779.7$; $P < 0.0001$) and males (wk: $\chi^2 = 1900.9$; $P <$ 0001; bait: $\chi^2 = 4087.7$; $P < 0.0001$). The pronounced temporal effect reflects the large increase in captures of both sexes over the course of the experiment. As with *B. dorsalis*, significantly greater numbers of *Z. cucurbitae* females were captured in traps baited with torula yeast borax solution than either the 2- or 3-component food cones ($P < 0.0001$ in both cases), whereas there was no difference in female captures between the 2 types of food cones ($P = 0.99$). However, unlike *B. dorsalis*, males of *Z. cucurbitae* also were

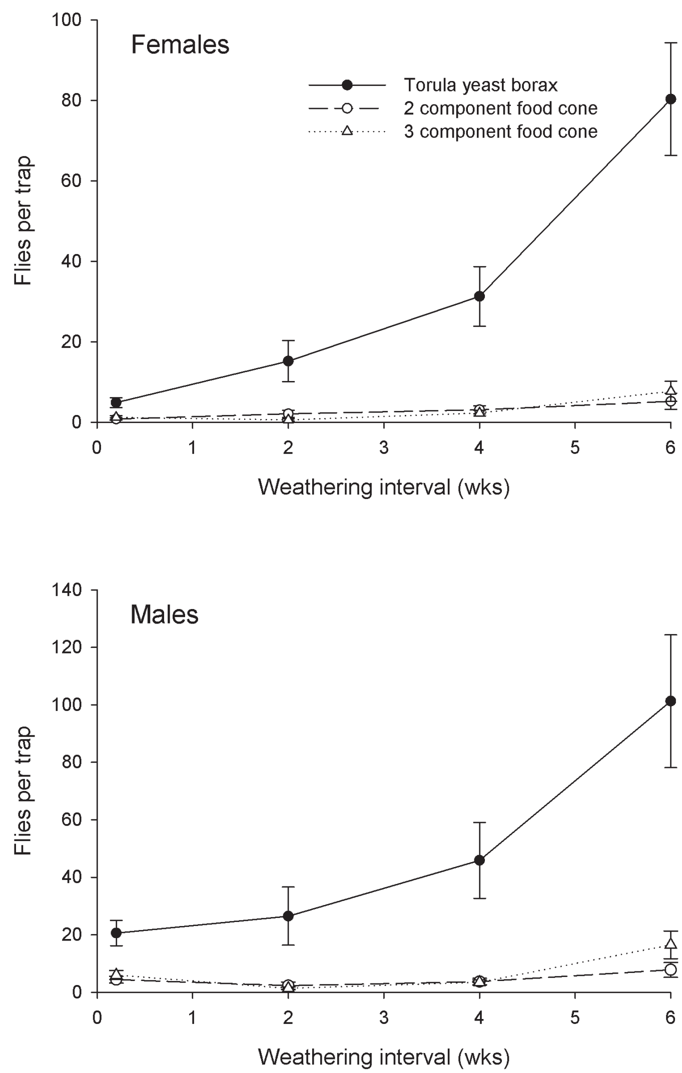


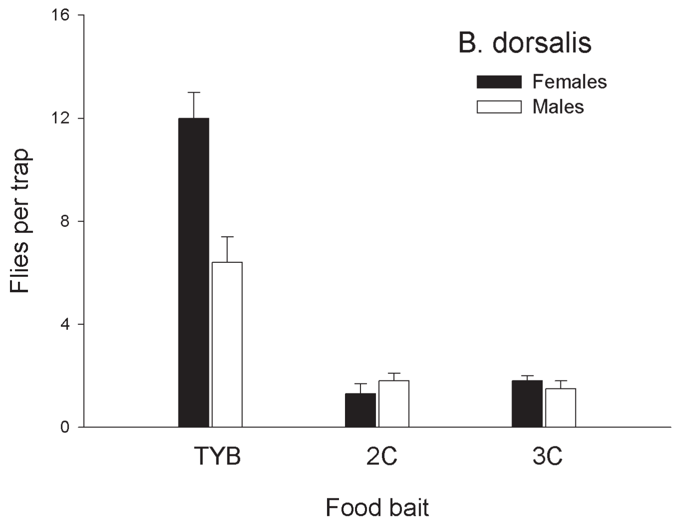
Fig. 2. Captures of wild *Zeugodacus cucurbitae* in traps baited with torula yeast borax solution, 2-component cones, or 3-component cones. Symbols represent means (± 1 SE); $N = 10$ traps per treatment per weathering interval.

captured more frequently in traps baited with torula yeast borax than in traps with 2- or 3-component food cones ($P < 0.0001$ in both cases). There was no difference in male captures between the 2 types of food cones ($P = 0.98$).

The sex ratio of captured *Z. cucurbitae* did not vary significantly over time ($\chi^2 = 1.6$; $P = 0.67$) or among baits ($\chi^2 = 0.2$; $P = 0.93$). On average, females represented 37.8% of total captures in traps baited with torula yeast borax ($N = 34$) compared to 37.0% and 30.1% of traps with 2- or 3-component food cones, respectively ($N = 10$ and 12, respectively; for all baits, only traps with ≥ 10 flies were considered).

RELEASE RECAPTURE

Data on captures of released *B. dorsalis* are presented in Fig. 3. For this species, food bait had a significant effect on captures of both females ($\chi^2 = 35.9$; $P < 0.001$) and males ($\chi^2 = 13.3$; $P = 0.001$). Captures did not vary significantly among replicates for either females ($\chi^2 = 2.7$; $P = 0.74$) or males ($\chi^2 = 1.2$; $P = 0.94$). The sexes showed similar responses to the different food baits; both females and males were captured in greater numbers in traps baited with torula yeast borax than traps baited with either 2- or 3-component food cones ($P < 0.001$ in both tests). For both sexes, captures did not differ between 2- and 3-component food cones ($P > 0.05$ in both cases).



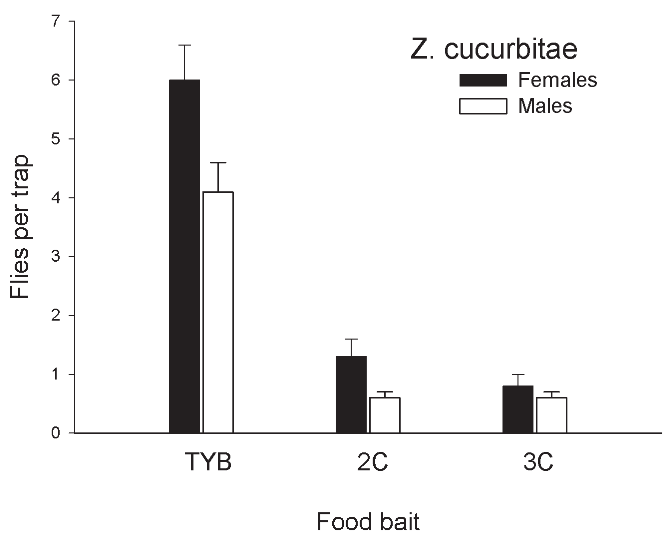


Fig. 3. Captures of release *Bactrocera dorsalis* (top) and *Zeugodacus cucurbitae* (bottom) in traps baited with torula yeast borax solution (TYB), 2-component cones (2C), or 3-component cones (3C). Bar heights represent means (± 1 SE); $N = 48$ traps per treatment (8 traps per replicate × 6 replicates).

Sex ratios of captured *B. dorsalis* varied significantly among the different food baits ($F_{2,15} = 11.5$; $P < 0.001$). On average, females constituted 65.5 ± 6.2% of the total catch for torula yeast borax traps compared to 40.8 ± 9.3% and 51.3 ± 5.1% for traps containing 2- and 3-component food cones, respectively ($P < 0.05$ for both tests). Sex ratios did not differ significantly between traps baited with 2- or 3-component food cones ($P > 0.05$).

Data on captures of released *Z. cucurbitae* are presented in Figure 3. For this species, food bait had a significant effect on captures of both females ($\chi^2 = 30.7$; $P < 0.001$) and males ($\chi^2 = 6.6$; $P < 0.001$). In contrast, there was no significant variation in captures of females ($\chi^2 = 0.9$; $P = 0.97$) or males ($\chi^2 = 0.01$; $P = 0.99$) among replicates. The sexes showed similar responses to the different food baits; both females and males were captured in greater numbers in traps baited with torula yeast borax than traps baited with either 2- or 3-component food cones ($P < 0.001$ in both tests). For both sexes, captures did not differ between 2- and 3-component food cones ($P > 0.05$ in both cases).

Sex ratios of captured *Z. cucurbitae* varied significantly among the different food baits ($F_{2,15} = 5.1$; $P = 0.02$). On average, females constituted 59.8 ± 4.0% of the total catch for torula yeast borax traps, and 66.6 ± 6.9% and 54.7 ± 6.5% for traps containing 2- and 3-component food cones, respectively. The post-hoc Tukey's test showed that a significant difference ($P < 0.05$) in sex ratio existed between 2- and 3-component food cones but not in any other pairwise comparison.

Discussion

Trapping wild flies revealed that, in general, torula yeast borax solution was significantly more attractive to *B. dorsalis* and *Z. cucurbitae* than 2- or 3-component food cones, a result different from that obtained for *C. capitata* or *A. suspensa* (Jang et al. 2007). This trend was evident for females of both species and males of *Z. cucurbitae*. Moreover, greater attractancy of torula yeast borax was noted even when the deployed food cones were relatively fresh. For example, when all baits were fresh (wk 0, Fig. 1), an average of 14 *B. dorsalis* females were captured in traps baited with torula yeast compared to approximately 7 females in traps baited with 2- or 3-component cones, respectively. Similarly, on average, 15.2 *Z. cucurbitae* females were captured in traps baited with torula yeast compared to less than 1 female in traps baited with 2- or 3-component cones, respectively, that had been weathered for only 2 wk (Fig. 2). Thus, the greater attractiveness of torula yeast borax solution did not appear to reflect declining attractiveness of the food cones over time but rather an inherent difference between the yeast solution liquid and the solid formulations. In contrast to this general trend, *B. dorsalis* males were found in significantly greater numbers in traps baited with food cones, and this finding was evident for newly deployed food cones as well as those weathered for 6 wk.

Data from wild populations also revealed a marked difference in the sex ratio of captured flies between the 2 study species. For *B. dorsalis*, catch was female-biased for all 3 food baits, and this was particularly pronounced for the torula yeast borax solution, where females comprised 81%, on average, of the total catch. Female proportions were lower for the 2 types of food cones but were still approximately 60% in both instances. In contrast, catch of *Z. cucurbitae* was male-biased, and females represented only 30% to 38%, on average, of the catch across all food baits. These findings are consistent with the limited data available. Leblanc et al. (2010) reported that females of *B. dorsalis* constituted 70% and 66% of total catch in traps baited with torula yeast borax or synthetic food components (presented in 3 separate packets), respectively (see also Shelly et al. 2020). Likewise, those authors reported that catch of *Z. cucurbitae* was strongly male-biased in traps having torula yeast borax or the synthetic food components. Thus, although scant, available data suggest that there is a marked sexual difference in response to food-based traps, with females of *B. dorsalis* attracted in greater numbers than conspecific males, whereas the opposite is true for *Z. cucurbitae*. Results from *C. capitata* and various *Anastrepha* species tend to show a female-bias in food-based traps (Epsky et al. 1999; Katsoyannos et al. 1999; Hall et al. 2005; Martinez et al. 2007), but the sex ratio may vary even among populations of the same species depending upon their age structure, which presumably influences the response of adults to food baits (Thomas et al. 2001). Data from different populations of *Z. cucurbitae* are needed to determine whether the male-bias observed in Hawaii is a location-specific trait or a general characteristic of the species.

The release-recapture experiment confirmed the variation in overall attractiveness among the food baits. As with the wild flies, released flies were caught in significantly greater numbers in traps baited with torula yeast borax than 2- or 3-component food cones, and this trend held for both sexes of both species. Also, in the release-recapture experiment, sex ratios showed the same trend noted for wild *B. dorsalis*, with females comprising a greater proportion of the total catch in traps containing torula yeast solution than traps containing food cones. Likewise, sex ratios for wild Z. *cucurbitae* were similar among the 3 food baitsand were similar between traps baited with torula yeast borax and traps baited with food cones, though a significant difference was not detected between traps containing 2- or 3-component food cones.

In conclusion, both trapping of wild flies and a release-recapture experiment showed that traps baited with torula yeast borax captured greater numbers of *B. dorsalis* and *Z. cucurbitae* than traps baited with 2- or 3-component food cones. For those trapping programs that have adopted food cones, the implications of this finding are perhaps less serious for *B. dorsalis*, because the male lure methyl eugenol is a powerful attractant and is considered an effective tool in detecting incipient populations of this species. By comparison, however, the male attractant (cuelure) used to monitor *Z. cucurbitae* populations is less potent and likely less effective in detecting invasive populations. For example, estimates based on mark-release-recapture studies conducted within the trapping system in southern California indicate that methyl eugenol-baited traps would have near certainty of detecting *B. dorsalis* populations having as few as 50 males, whereas the corresponding number for cue-lure traps and detection of *Z. cucurbitae* is 350 males, a 7-fold difference (McInnis et al. 2017). Given a relatively weak male attractant, the type of food-based trap deployed would appear to gain importance in the case of *Z. cucurbitae* and possibly other related species.

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