Abstract. Methyl eugenol (4-allyl-1-2-dimethoxybenzene-carboxylate) is a commonly occurring plant phenylpropanoid which is a highly attractive lure to the male oriental fruit fly, &Bactrocera dorsalis (Hendel). Twelve plastic bucket traps were hung in a row of Norfolk pine trees. Each trap contained either 4 ml of methyl eugenol on a cotton dental wick, 2 g methyl eugenol plastic matrix (hereafter called a “plug”), or an untreated dental wick (as a control). After 5 months and 12 days the control wick was charged with 2 ml of liquid methyl eugenol and was subsequently recharged every two weeks. Results showed that the 4ml treated wick and the 2 gram plastic methyl eugenol plug had no significant difference in catch per trap per day for the first 2 months. Although the plug actually averaged higher catch the difference was not significant by analysis of variance with or without repeated measures. Using the repeated measures analysis, date was the most significant factor, although there was no interaction between the effects of lure and date. In the subsequent 2 months, the plastic lures continued to catch at a declining rate (mean 36.7 ± 15.0% of the 4 ml lure on a cotton wick). The data suggest that the plastic lure could be used for 2 months where temperatures are not extreme. In exclusion programs maximum rate of catch is a requirement, but that is not necessary for population suppression. For the latter purpose, the 2 ml methyl eugenol plug could be used longer than two months, or the matrix could be adjusted to hold a larger volume of lure. A plug containing 5 g of methyl eugenol was able to catch flies efficiently for one year. Fly capture was more efficient in one-way entrance traps than in traps containing toxicant.

Key Words: &Bactrocera dorsalis, methyl eugenol, male annihilation, one-way trap, Area Wide Program

Introduction

The oriental fruit fly &Bactrocera dorsalis was first introduced to Hawaii in 1945. It soon became an agricultural pest, infesting more than 150 species of fruits and vegetables in Hawaii. &Bactrocera is a tephritid fly genus of ca. 440 species distributed primarily in tropical Asia, the South Pacific, and Australia (Vargas et al. 2000) This accidental introduction severely affected the local, national and international market for Hawaiian produce. Because of this constant threat of introducing fruit flies to the continental United States, expensive post harvest quarantine treatments are mandatory for exported fruit that are potential hosts for fruit flies. The Hawaiian Islands are infested with some of the largest known populations of B. dorsalis in the world (Vargas et al. 2000). Due to this fact, the growing of fruit fly susceptible crops is increasingly difficult.

A program funded by the USDA called the Hawaii Area Wide Fruit Fly Pest Management Program was initiated in 2000 to transfer suppression technology to the state’s grow-
ers and gardeners (Vargas et al. 2003). Area-wide fruit fly control methods vary according to species, infestation levels, and environmental factors (Vargas et al. 2000). Such methods include the use of sterile flies, parasitoids, bait sprays, male annihilation and fruit sanitation. Male annihilation of the oriental fruit fly has been proven successful in the islands of Rota (Steiner et al. 1965) and Okinawa (Koyama et al. 1984). These male lures are used in large scale detection-trapping arrays in the continental United States where there is a constant threat of accidental introduction of fruit fly species from infested fruit smuggled through quarantine check points (Cunningham et al. 1990). Such an introduction in California would prove disastrous to their 14 billion dollar fruit and vegetable industry (Cunningham et al. 1990). For that reason the lures used in the exclusion programs need to be at maximum performance levels to insure accurate detection. But in an area of established fruit fly population, like Hawaii, the longevity of a lure's performance becomes more important. Where the cost of trapping dictates the longest possible deployment of lures, it is useful to know the lifespan of the lure.

The attractant lure for male *B. dorsalis* is liquid methyl eugenol (4-allyl-1, 2-dimethoxybenzene-carboxylate) (Vargas et al. 2000) a commonly occurring plant phenylpropanoid (Metcalf 1987) applied to a cotton wick and hung inside of a water trap. Although methyl eugenol is the most attractive fruit fly lure so far developed, it is also a suspected carcinogen. It has recently been reported to induce hepatic tumors in mice (Miller et al. 1983). The related phenylpropanoid eugenol shows equivocal evidence of carcinogenicity in mice (Gold et al. 1993).

The purpose of this research was to test the strength of attraction and longevity of the cotton-wick lure (4 ml liquid methyl eugenol) vs. a plastic matrix containing 2 grams of methyl eugenol. The advantage of the plastic matrix (or plug), produced by Scentry Biologicals Inc., is that it can be manufactured in individually-sealed packets, so there is no unnecessary exposure of the handler to the vapors. The future benefit for the control of *B. dorsalis* is that this delivery system is safer for the user because it keeps contact with the lure to a minimum. These lures will be easier to deploy because no preparation of lure on wicks is required. The plastic matrix can be sized to allow extended field use, and has potential for use in toxicant-free traps, such as the one-way entrance trap proposed by Tan (1985). All these advantages increase the likelihood that the plastic matrix lure will be registered for widespread commercial use, provided that the effectiveness of the lure-delivery system can be demonstrated.

### Materials and Methods

**Materials.** Traps were made from 1 liter linear polyethylene buckets (408-30N, Highland Plastics, Mira Loma, CA). The dimensions of the buckets were 11.43 cm h, 11.90 cm in dia. and 36 grams in weight. Each bucket had four holes (1.91 cm dia.) along the sides which served as fly entrances. Also, 8 holes (0.16 cm dia.) were drilled on the bottom which served as drainage for any water that collected in the trap. A 0.48 cm hole was drilled in the middle of the trap lid. A 20 gauge insulated copper wire was cut to about 40.64 cm with 12.70 cm of insulation stripped from the bottom. This exposed part of the wire provided better adhesion to the bucket when glued on. The wire was inserted into the hole on the trap lid, bent where the insulation begins, glued, and then bent again to form a hook.

**Chemicals.** For this test, two formulations of the male-lure, methyl eugenol, were used. The first formulation was the liquid lure itself. The second was a plastic matrix (a polymerized mixture that is the proprietary invention of Scentry Biologicals Inc, Billings, MT, hereafter referred to as a plug). These plugs contained 2 g or 5 g of the active ingredient, methyl eugenol, in trials 1 and 2 respectively. Hercon® Vaportape™ II strips (Hercon Environmental,
Emigsville, PA) were also hung inside the traps to provide a toxicant to kill flies after entering the traps. This plastic product is 2, 2-Dichlorovinyl dimethyl phosphate (DDVP) which is released as a gas at a rate determined by vapor pressure, humidity and temperature.

**Trail 1.** A total of 12 traps were made for the test. Eight of the traps used wicks and four used the plugs. The wicks (Henry Schein Inc, Melville, NY) used were 3.81 cm long and 0.952 cm dia. and were placed in plastic basket, hung in the center of the bucket lid upon the wire hanger on the bottom side of the trap lid. Four of the traps were treated with 4 ml of liquid methyl eugenol, four used the plug and four were left untreated and acted as the control. All of the traps included the pesticide strip. Traps were deployed on June 18th 2003 upon the grounds of the Hamakua Spring Farm near Pepeekeo on the east coast of the island of Hawaii. The placements of traps were randomly assigned. The traps were placed in a row of Norfolk pine (Araucaria heterophylla) trees with every other tree having a trap on it. Each trap was ca. 12.5 m apart and these were hung at ca.1.524 m above the ground.

Beginning December 12, 2003, after 5 months and 10 days the dry control wick was charged with 2ml of liquid methyl eugenol, and every two weeks thereafter. It is know from extensive USDA data that wicks, recharged at this rate, provide an assured maximum release of lure. These provide as a standard of comparison for weathered traps. Neither the 4 ml wicks nor the 2 g plugs were recharged for the duration of the test.

**Trial 2.** On Feb. 5 2004 traps were deployed at the Hilo orchard of Janice Roehrig in a hedgerow of hibiscus (Hibiscus rosa-sinensis). Four traps contained Vaportape™ II (as previously described). On Mar. 5 2004, 4 additional traps were deployed without toxicant. In the entrance holes of these latter 4 traps, 4 microcentrifuge tubes (capacity 1.5 ml, 11 mm o.d., 41 mm length, Fisher Scientific, Pittsburgh, PA) were inserted. The tip of the microcentrifuge tube had been cut off at the 0.1 ml mark, and the caps were left open during deployment of the traps. This provided one-way entrances which facilitated the capture of flies without toxicant. All 8 traps contained a 5 g methyl eugenol plug (previously described). The treatments were randomly assigned to the trapping locations which were separated by ca. 2 meters and ca. 1 meter high along a straight line on the border of the orchard. The trial was continuous using the same lures until Feb 17 2005. Vaportape™ II strips were replaced on May 6th, Aug. 31st and Nov. 23rd 2004.

**Analysis.** Analysis and graphs were done using the SAS version 8.02 and Microsoft Excel respectively. SAS was used to calculate the means of the overall trap catch per day, overall means from start to finish, and the means for flies per trap per day for the methyl eugenol wick and the methyl eugenol plastic matrix (plugs). The untreated control wicks were not used in the calculations or graphs from the start to Dec 12 2003 because they did not catch any flies during that period. Trap performance was compared over the 1st and the 2nd month using general linear models (GLM) analysis. Because of the large change in population over time, the data was also analyzed by GLM, repeated measures analysis.

**Results**

**Trial 1.** In the first 2 months there was no difference in catch of flies per trap per day between the traditional 4 m liter treated wick (4.59 ± 0.78, n=24) and the 2 gram plastic methyl eugenol plug (6.60 ± 0.78, n = 24) (Fig. 1A). Although the plug actually averaged higher catch, the difference (F_{1,36} = 3.31, P<0.0771) was not significant at the 0.05 level. Using the repeated measures analysis to isolate the effect of the daily decline in trap catch, date was the most significant factor (F_{5,30} = 23.09, P<0.0001), although there was no interaction between the effects of lure and date. Repeated measures did not reveal a difference in catch between the two lures. In the first two months the decrease in fly catch can be attributed to a decline in the general population of B. dorsalis. Throughout the test (Fig. 1B),
fluctuations in the population of *B. dorsalis* can be seen. *B. dorsalis* is present in high numbers during the summer months and during the winter months, and declines sharply in August and March (Fig. 2). This is obvious, because, as the fly population recovered in September 2003, the catch rates of the 4 ml wicks increased, even though they were not recharged. The increased lure catch could not be explained by temperature, because the weather is actually cooler in Sep and Oct. The fact that the fly population remained high through February 2004 is confirmed by the fact that the recharged 2 ml wick was catching as many flies as the 4 ml wick at its peak in late November. Therefore, the average of all the lure treatments gives a rough estimate of the overall population fluctuation even though some lures may have declined in attractiveness.

**Figure 1a.** Mean and standard error of male oriental fruit fly catch per trap per day for each individual lure-charge treatment. **1b.** Rate of decline in trap captures for the two lures during the first two months of the test.
After the 2-month period, the traditional wick increased in catch whereas the plastic plug continued to catch within a changing proportion ($0.367 \pm 0.150$) of the trapping rate of the 4 ml wick for ca. 4 months. The increased trapping rate was most likely due to the rise in the population of *B. dorsalis*. This rise was also reflected in the plug lure catch but at a much reduced level. By the 4th month the 4 ml methyl eugenol wick began to decline in attractiveness. In the last 3 months the control wick (no methyl eugenol) was changed to a wick freshly-charged with 2 ml methyl eugenol, which was then recharged every 2 weeks. The freshly-charged wicks caught very high numbers compared to both the traditional wicks and the plugs which had declined to ca. 0 flies/trap/day. When the freshly-charged wick was added to the test on Dec. 12, 2003, it averaged 14.26 $\pm$ 2.60 flies/trap/day (FTD) compared to the 4ml wick (0.094 $\pm$ 0.51) and the plastic plug (1.10 $\pm$ 0.29). The intrinsic rate of decline in lure strength cannot be determined in a fluctuating population like this, but the catch ratios (4 ml wick: fresh 2 ml wick) at ca. 5.5 months was 0.232. The ratio of 2 ml plug to freshly-charged 2 ml wick at ca. 5.5 months was 0.130. By the 7th month those ratios had declined to 0.046 and 0.008 respectively, at which point the plug and 4 ml wick were catching minimal numbers of flies whereas the catch of the freshly-charged wicks peaked. Over the last 2 months, the mean ratio of catch for the plastic plug and the 4 ml wick to the freshly-charged wick was 0.077 $\pm$ 0.32 and 0.035 $\pm$ 0.014 respectively. The test was terminated on Mar. 18, 2004 because even the freshly-charged wick catch had declined sharply.

**Trial 2.** Lure plugs with 5 g of methyl eugenol were tested over a one-year period. These tests indicated that the 5 g ME lure caught at a comparable rate for the first 10 months. In the last two months there was a decline in mean flies/ trap/day until the catch approached 0 in the traps containing Vaportape™ II ($y = -0.0185x + 709.69$, $R^2 = 0.3072$). Nevertheless, the one-way entrance traps which did not contain a toxicant, consistently caught at a higher

![Figure 2](image-url)
rate (9.03 ± 0.86 FTD, n = 84) than those containing toxicant (4.19 ± 0.93 FTD, n = 110) (F \( _{2,319} = 12.91 \ P<0.0001 \)). The one-way traps were still catching flies at 12 months (\( y = -0.0097x + 380.68, \ R^2 = 0.0147 \)). The population of flies was frequently fluctuating over the period in which the five gram ME lure plugs were deployed. The highest catch occurred at 5 months into the test.

There is evidence that the Vaportape™ II created some repellency, as indicated by the fact that the difference in catch between toxicant and non-toxicant traps was greatest immediately after toxicant was replaced (specifically, there was a 2.4, 9.1, and 3.5 fold difference between the treatments after the 1\(^{st}\), 2\(^{nd}\) and 3\(^{rd}\) recharge respectively). Whereas just prior to recharge the differences were 1.9, 2.2, and 1.4 fold respectively.

**Discussion**

In this test we have shown that, under these environmental conditions (ca. 17 to 28\(^{\circ}\) C, and ca. 80 to 98% RH), a 2 gram methyl eugenol plastic matrix (plug) lure will maintain equivalent catch to a 4ml cotton wick with liquid methyl eugenol for 2 months. However, it continues to catch from the third to the sixth month at a rate averaging slightly over one third of the catch rate of a freshly charged wick. After that it declines to virtually 0 catch by 8 months. The same plastic matrix in a formulation with 5 g of methyl eugenol appeared to have more longevity than cotton wicks of similar charge (4 ml). The longevity of the plastic matrix lure was more apparent in traps without toxicant. The cotton wick with 4 ml methyl
eugenol is currently used by the USDA Area Wide Program for a 3-month deployment, which is within its range of performance (USDA unpublished data). By the time these tests were completed, Scentry Biologicals was still awaiting registration of the lure in order to commercialize the production of the plastic matrix with lure. The USDA's Area Wide Program is currently testing the public acceptance of this presentation of Oriental fruit fly lure in 2 g and 10 g plastic matrices in hopes that the public will more readily accept fruit fly trapping as a way of life for fruit growers and gardeners in Hawaii.

Before 2001, the only legal use of lures in Hawaii was for monitoring population, and only water could be used to kill (drown) the flies. In 2001, the Area Wide Project registered (Hawaii State permit, 24C for 5 years) the use of Dibrom concentrate® (AMVAC Chemical Corp., Los Angeles, CA) in a mixture with liquid methyl eugenol. Although it is registered for 5 years and may be extended for an additional 5 year period, Dibrom concentrate® is not used by growers because of the many handling hazards and regulations associated with it. In addition, this product is only available in a volume (208 l drum, AMFAC) that growers in this state would not be willing to purchase, handle and store. Another toxicant, DDVP (synonym: dichlorvos) in the form of Vaportape™ II is registered for use in Hawaii against fruit flies. Unfortunately the registration does not stipulate that it can be used with fruit fly lures, and the state authorities question whether the mixture of volatile components of DDVP and lure require a separate registration of the mixture.

Despite this regulatory debate, the advantages of the individually-packaged Vaportape™ II strips include their simplicity of application and safer handling. The USDA is currently using this toxicant in its Hawaii Area Wide Fruit Fly Pest Management Program. However, registration of this product on any long term basis may prove difficult. Organophosphate toxicants may not be available or allowed for use with fruit fly lures in future. Currently there are no traps commercially available that use a lure without a toxicant or water, but research into the development of a one-way entrance trap was initiated in this trial and is being pursued by the Pacific Basin Agricultural Research Center, United States Department of Agriculture (USDA), Hilo, Hawaii.

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Literature Cited


