

EFFECTS OF SUGAR/FLOUR SPHERES COATED WITH PAINT  
AND INSECTICIDE ON ALIGHTING FEMALE *CERATITIS*  
*CAPITATA* (DIPTERA: TEPHRITIDAE) FLIES

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ABSTRACT

We studied the behavior and fate of mature, wild-origin *Ceratitis capitata* (Wiedemann) females allowed to feed on 7-cm-diam spheres comprised of a mixture of sugar, flour and glycerin and coated with yellow latex paint containing either no insecticide, dimethoate (1.5% a.i.) or imidacloprid (1.5% a.i.). Females feeding on imidacloprid-treated spheres for 20 sec exhibited very little tendency to forage within host plants or to lay eggs either shortly after or 24 h after feeding, and suffered high mortality within 48 h. In contrast, females feeding on dimethoate-treated spheres for 180 sec exhibited, shortly thereafter, a tendency to forage within host plants and to lay eggs about equal to that of females feeding on untreated spheres, although they suffered high mortality within 24 h. In a field test, imidacloprid-treated sugar/flour spheres provided a significant level of protection of fruit from oviposition by *C. capitata* during 24 h periods (equal to that provided by sticky yellow spheres), whereas dimethoate-treated spheres did not. Further research on long-term activity of pesticide residue and on sphere performance under natural conditions will be necessary, however, before sugar/flour spheres coated with yellow latex paint and insecticide can be recommended for control of *C. capitata*.

Key Words: Mediterranean fruit flies, imidacloprid, dimethoate, spheres

RESUMEN

Estudiamos el comportamiento y el destino de moscas hembra maduras de *Ceratitidis capitata* (Wiedemann) de origen silvestre a las que se les permitió alimentarse sobre esferas de 7 cm de diámetro compuestas de una mezcla de azúcar, harina y glicerina cubiertas con pintura de látex amarilla que contiene ya sea ningún insecticida, dimetoato (1.5% i.a.) o imidacloprid (1.5% i.a.). Las moscas hembra que se alimentaron en esferas con imidacloprid por 20 segundos exhibieron una muy baja tendencia a alimentarse en plantas hospederas o a poner huevecillos poco después de alimentarse o 24 horas después de alimentarse y sufrieron una tasa de mortandad alta dentro de un período de 48 horas. En cambio, las hembras que se alimentaron en esferas con dimetoato por 180 segundos exhibieron poco después niveles de tendencia a alimentarse en plantas hospederas y a poner huevos aproximadamente igual a los demostrados por las hembras que se alimentaron en esferas no tratadas con insecticidas, aunque sufrieron una tasa de mortandad alta dentro de un período de 25 horas. En un experimento de campo, esferas de azúcar y harina tratadas con imidacloprid proporcionaron un nivel significativo de protección a la fruta en contra de oviposición por *C. capitata* durante períodos de 24 horas (igual al que proporcionaron las esferas amarillas pegajosas), mientras que las esferas tratadas con dimetoato no lo lograron. Es necesario hacer investigación adicional sobre la actividad a largo plazo de residuos de pesticidas y sobre el funcionamiento de las esferas bajo condiciones naturales antes de que puedan ser recomendadas las esferas amarillas de azúcar y harina cubiertas con pintura de látex e insecticida para el control de *C. capitata*.

The Mediterranean fruit fly, *Ceratitis capitata* (Wiedemann), is an important pest of fruits and vegetables on several continents. A variety of traps has been developed for capturing *C. capitata* females and males (Heath et al. 1995), including sticky-coated fruit-mimicking sphere traps (Nakagawa et al. 1978; Cytrynowicz et al. 1982; Katsoyannos 1987; Katsoyannos & Hendrichs 1995). Yellow spheres have proven to be the most attractive colored spheres for *C. capitata* females, especially when 7 cm diam in size (Katsoyannos 1987).

Another tephritid, the apple maggot fly, *Rhagoletis pomonella* (Walsh), has been successfully controlled in commercial apple orchards using 8-cm-diam sticky-coated red wooden spheres hung (when unbaited) on every tree in an orchard or (when baited) on perimeter apple trees so as to surround an orchard (Prokopy & Mason 1996). Because considerable labor and expense are associated with cleaning such spheres every other week to maintain fly-capturing effectiveness (Duan & Prokopy 1995b), an alternative to sticky as the fly killing agent has been sought in the form of a mixture of pesticide, fly feeding stimulant and residue extending agent that could be applied to the sphere surface and kill alighting flies through ingestion of pesticide (Duan & Prokopy 1995b). A far less amount of pesticide is required to achieve mortality via ingestion than through tarsal contact alone (Duan & Prokopy 1995a). One shortcoming of this approach, however, has been rapid disappearance of fly feeding stimulant (sugar) during rainfall (Duan & Prokopy 1995a). To address this shortcoming, a new type of sphere has been created to replace wood as the sphere body (Hu et al. 1998). It consists of sugar entrapped in a mixture of gelatinized flour and glycerin. These ingredients are formed into a sphere, which is then dried and coated with a mixture of latex paint and insecticide. A sphere of this sort maintains a continuous supply of fly feeding stimulant on the sphere surface, even under rainfall, with latex paint acting as a residue extending agent for the insecticide (Hu et al. 1998). To date, two insecticides have shown more promise than any others tested when combined with latex paint applied to sugar/flour spheres: dimethoate (Duan & Prokopy 1995a) and imidacloprid (Hu & Prokopy 1998).

Here, we evaluated the potential of insecticide-treated yellow-colored sugar/flour spheres for use in controlling *C. capitata* females by comparing the effectiveness of dimethoate and imidacloprid. First, we asked which of these two insecticides ultimately yielded the greatest reduction in oviposition and the greatest mortality of alighting females. Next, we asked which of these two insecticides most strongly reduced intra-plant foraging and ovipositional activities of females between the time of alighting on spheres and the occurrence of mortality. Finally, we asked which of these two insecticides on spheres offered the greatest degree of protection of fruit against *C. capitata* oviposition.

#### MATERIALS AND METHODS

*C. capitata* used in all greenhouse trials originated as larvae from infested fruit collected in Hilo, Hawaii. Upon eclosion, both sexes were maintained together in 30 × 30 × 30 cm cages supplied with enzymatic yeast hydrolysate, sucrose and water until females were mature and tested at 14-21 days of age. Females were deprived of all food, but not water, 18 h before initial testing.

Spheres used in all experiments were similar to those described by Hu et al. (1998). Sucrose (60g) was dissolved in fructose syrup (55 ml), water (40 ml) and glycerin (20 ml), following which pregelatinized corn flour (50g) and wheat flour (50g) were added, mixed and heated in a microwave oven. The resulting dough was allowed to cool before it was formed into a 7-cm-diam sphere, threaded with a wire to facilitate

hanging. It was then dried in a regular oven, after which it received a coat of gloss yellow latex enamel paint (Glidden, Cleveland OH) as protectant. Then spheres received a second coating of the same paint containing either 1.5% a.i. of dimethoate (Digon 400, Wilbur-Ellis, Fresno CA), 1.5% a.i. of imidacloprid (Provado, Bayer, Kansas City, MO) or no insecticide, which we term dimethoate-treated, imidacloprid-treated or untreated spheres, respectively. Due to constraints of fly availability, we began testing one day after spheres received the second coating of paint. To elicit fly feeding response, 20% sucrose was added to the paint applied in the second coating. Three days are usually required for sufficient sucrose from the sphere body to penetrate paint and stimulate fly feeding (Hu et al. unpublished). For brevity, we hereafter consider the second coating simply as a mixture of latex paint and insecticide, not explicitly acknowledging the sucrose present in the mixture at application.

Greenhouse experiments were conducted in  $70 \times 70 \times 70$  cm screen cages (open to the front), and protected above from direct sunlight with a covering of white paper. Each cage contained a small, non-fruiting potted coffee plant whose canopy was about 50 cm diam and had about 50 leaves. A sphere was hung near the front edge of the canopy. During 0900-1600 h, we released females singly onto the surface of a sphere, using a small piece of paper dipped in a 20% sucrose solution and attached to a probe to transfer the fly from a holding cage to the sphere. In the first greenhouse experiment, each female was allowed to remain on a sphere until it departed or fell due to poisoning. Total duration of stay and total time of feeding were recorded. Each fly was then transferred immediately to a 120 cm<sup>3</sup> plastic cup containing sucrose, water and an uninfested kumquat as an ovipositional site. After 48 h, the female was classified as being alive, dead or moribund (able to move but not crawl or fly and considered dead in data analysis) and the number of eggs laid was counted.

In the second greenhouse experiment, females were again transferred individually onto a sphere but allowed to feed only for a prescribed maximum amount of time, which was equivalent to the median duration of feeding in the first experiment: 220, 180 and 20 sec, respectively, for untreated, dimethoate-treated, and imidacloprid-treated spheres. Following feeding for this length of time or following departure or falling from a sphere (if a female left before reaching this allowable duration of feeding), we immediately transferred the female onto a leaf at the center of the plant canopy and removed the sphere from the cage. We recorded duration of fly stay on the plant (up to 15 min) and counted all leaves visited by flight or crawling within this period as a measure of foraging propensity. Thereafter, the female was transferred to a kumquat fruit hung from the plant. We counted all ovipositional bouts of the female during the next 5 min as a measure of propensity to oviposit. After this the female was transferred to a plastic cup with sucrose and water for 24 h, at which time females still alive were again assessed by repeating the above protocol.

In a field experiment, we compared the number of eggs laid by wild-population *C. capitata* females in kumquats protected by pesticide-treated or sticky-coated sugar/flour spheres or in unprotected kumquats. The experiment was conducted in a coffee plantation (on Kauai) harboring a moderate population of females that had virtually no access to natural oviposition sites because nearly all coffee berries had been picked or fallen. About 3 m from the end of each of 20 rows of coffee plants and about 10 m from the nearest neighboring test sites, we hung two uninfested kumquats about 6 cm apart, attached to branchlets by twist ties. We also hung two same-type spheres, each about 12 cm from the nearest kumquat. We cleared the area nearby of leaves to permit visibility of fruits and spheres. Each site was baited with an aqueous extract of ripe coffee fruit as an ovipositional attractant (Prokopy et al. 1997) and an aqueous solution of Nulure as a feeding attractant (Steiner 1952; Wakabayashi and Cunningham 1991). Solutions were applied to cotton dental wicks in separate glass vials. There

TABLE 1. BEHAVIOR, OVIPOSITIONAL PROPENSITY AND FATE OF *CERATITIS CAPITATA* FEMALES DURING OR AFTER EXPOSURE ON YELLOW PAINT/SUGAR-COATED SUGAR/ FLOUR SPHERES IN GREENHOUSE ASSAYS.

Parameter Measured	No. Females Tested	Type of Sphere		
		Untreated	Treated with Dimethoate	Treated with Imidacloprid
Mean Duration of Stay (sec) <sup>1</sup>	20	564a	344b	238b
Mean Duration of Feeding (sec) <sup>1</sup>	20	333 a	231a	42b
Mean No. Eggs Laid when Confined with Kumquats during Next 48 h <sup>1</sup>	20	9.9 a	1.0b	1.0b
% Mortality after 48 h <sup>2</sup>	20	5	90	85

<sup>1</sup>Values within the same row followed by the same letter are not significantly different according to one-way ANOVA (following square root transformation) and the least significant difference test criterion at the 0.05 level. For mean duration of stay,  $F = 7.67$ ,  $df = 59$ ,  $P \leq 0.001$ . For mean duration of feeding,  $F = 10.61$ ,  $df = 59$ ,  $P \leq 0.0001$ . For mean number of eggs laid,  $F = 23.99$ ,  $df = 59$ ,  $P \leq 0.000$ .

<sup>2</sup>There is a significant difference among values in this row according to a Chi-square test for heterogeneity ( $P \leq 0.0001$ ).

were five replicates of each of four treatments: no spheres, or sugar/flour spheres coated either with sticky, with paint containing 1.5% a.i. dimethoate, or with paint containing 1.5% a.i. imidacloprid. Initially, we included pesticide-free sugar/flour spheres as a fifth treatment. Unfortunately, on the first day, curious bypassers damaged some of these spheres. Because we had no replacements, we were obliged to begin the experiment anew without this treatment. Treatments within a replicate were rotated daily for 4 days i.e. until each treatment was at each site once. Kumquats were removed daily for counting eggs and replaced with fresh kumquats. Odor attractants were renewed daily.

All data obtained, except those analyzed as proportions, were subjected to square root transformation to stabilize variance. For data in Table 1, differences in percent mortality among treatments were compared using a  $\chi^2$  test for heterogeneity. All other data in Table 1 were subjected to one-way ANOVA. In Table 2, duration of fly residence on plants was divided into 3 groups (1-120 sec, 121-300 sec and 301-900 sec). Data were analyzed using  $\chi^2$  tests for heterogeneity. Other data in Table 2 were subjected to one-way ANOVA (for data 0 h after exposure) or Kruskal-Wallis nonparametric one-way ANOVA (for data 24 h after exposure). Field test data in Table 3 were subjected to one-way ANOVA.

## RESULTS

In the first greenhouse experiment (Table 1), females stayed significantly longer on untreated than on dimethoate- or imidacloprid-treated spheres and fed significantly longer on untreated and dimethoate-treated spheres than on imidacloprid-treated spheres. During the next 48 h, under confinement with food and fruit, females that had been on untreated spheres laid about 10 times more eggs than females that had been on dimethoate- or imidacloprid-treated spheres. At 48 h, few females that had been on untreated spheres were classified as dead compared with females on insecticide/sugar treated spheres (Table 1).

TABLE 2. FORAGING BEHAVIOR OF *C. CAPITATA* FEMALES ON HOST PLANTS AND SUBSEQUENT OVIPOSITIONAL PROPENSITY AND FATE FOLLOWING FEEDING FOR 220, 180 OR 20 SEC, RESPECTIVELY, ON UNTREATED, DIMETHOATE-TREATED OR IMIDACLOPRID-TREATED YELLOW PAINT-COATED SUGAR/FLOUR SPHERES IN GREENHOUSE ASSAYS.

Parameter Measured	Type of Sphere to Which Female Was Exposed before Transferred to Plant at								
	0 h after Exposure					24 h after Exposure			
	No. Females Tested	Untreated	Treated with Dimethoate	Treated with Imidacloprid	No. Females Tested <sup>3</sup>	Untreated	Treated with Dimethoate	Treated with Imidacloprid	
% of Females Staying on Plant for	120 sec <sup>1</sup>	15	100	100	53	14, 3, 8	93	67	100
	300 sec <sup>1</sup>	15	73	93	40	14, 3, 8	79	0	100
	900 sec <sup>1</sup>	15	40	80	20	14, 3, 8	71	0	100
Mean No. Leaves Visited <sup>2</sup>	15	7.0a	5.2a	0.6b	14, 3, 8	2.6	0.0	0.3	
Mean No. Flights to Leaves <sup>2</sup>	15	6.1a	4.3a	0.6b	14, 3, 8	2.8	0.0	0.0	
Mean No. Ovipositional Bouts <sup>2</sup>	15	0.9a	1.0a	0.1b	14, 3, 8	1.0	1.0	1.0	
% Mortality after 24 h <sup>1</sup>	15	7	80	47	—	—	—	—	

<sup>1</sup>For each row at 0 h, according to Chi-square tests for homogeneity, probability of a significant difference among values was  $p \leq 0.0003$ , 0.006, 0.004, and 0.0003, respectively, for 120 sec, 300 sec, 900 sec and % mortality; for each row at 24 h,  $p \leq 0.189$ , 0.002, and 0.005, respectively, for 120 sec, 300 sec, and 900 sec.

<sup>2</sup>At 0 h after exposure, values within the same row not followed by the same letter are significantly different according to one-way ANOVA (following square root transformation) and the least significant difference test criterion at the 0.05 level. For number of leaves visited,  $F = 10.27$ ,  $df = 44$ ,  $P \leq 0.000$ . For mean number of flights to leaves,  $F = 2.15$ ,  $df = 44$ ,  $P \leq 0.002$ . For mean number of ovipositional bouts,  $F = 5.73$ ,  $df = 44$ ,  $P \leq 0.006$ . At 24 h after exposure, probability of a significant difference (based on Kruskal-Wallis nonparametric one-way ANOVA) among values within a row was  $p \leq 0.007$ , 0.0001 and 0.126, respectively, for number leaves visited, number flights and number ovipositional bouts.

<sup>3</sup>Number females tested for untreated, dimethoate and imidacloprid spheres, respectively.

TABLE 3. PROTECTION OF KUMQUAT FRUIT BY PAINT/SUGAR-COATED SUGAR/FLOUR SPHERES AGAINST OVIPOSITION BY *C. CAPITATA* FEMALES IN THE FIELD.

No. Replicates Per Treatment	Mean No. Eggs Laid in Kumquats Protected by <sup>1</sup>			
	No Spheres	Dimethoate Spheres	Imidacloprid Spheres	Sticky Spheres
20	18.3a	14.5ab	7.4b	8.3b

<sup>1</sup>Values followed by the same letter are not significantly different according to the least significant difference test criterion at the 0.05 level.  $F = 3.50$ ,  $df = 19$ ,  $P \leq 0.033$ .

In the second greenhouse experiment (Table 2), when assessed for propensity to forage on fruitless coffee plants immediately after feeding on a sphere for an amount of time equivalent to the median value observed in the first greenhouse experiment, females from imidacloprid-treated spheres behaved significantly different from females on untreated or dimethoate-treated spheres. The former visited only 11% as many leaves and made only 14% as many flights as females from dimethoate-treated spheres, which were not significantly different in these characteristics from females from untreated. Moreover, when exposed to kumquat fruit for 10 minutes upon departure or removal from a plant, females from imidacloprid-treated spheres engaged in only about 10% as many ovipositional bouts as females from dimethoate-treated or untreated spheres. At 24 h, only 7% of females from untreated spheres were dead compared with 80 and 47%, respectively, of females from dimethoate- and imidacloprid-treated spheres. When, in the second greenhouse experiment, females alive at 24 h post-exposure to spheres were re-evaluated for foraging propensity, essentially none of those from dimethoate- or imidacloprid-treated spheres visited any leaves by either flying or crawling (Table 2). Those from imidacloprid-treated spheres remained largely motionless. Numbers of ovipositional bouts per female were initially about the same as those found at 0 h after exposure to spheres for each treatment.

In the field experiment, imidacloprid-treated spheres protected kumquats over 24 h periods against oviposition by wild *C. capitata* females to a degree equal to that afforded by sticky spheres and numerically (although not significantly) better than that provided by dimethoate-treated spheres (Table 3). Among all tephritid females captured on the sticky spheres, 94% were *C. capitata*, suggesting a very high probability that the tephritid eggs in the kumquats were deposited by *C. capitata*, not by other tephritid flies.

#### DISCUSSION

Our findings indicate that sugar/flour spheres containing the insecticide imidacloprid at 1.5% active ingredient in the surface coating of yellow latex paint are highly effective in immediately immobilizing *C. capitata* females that alight and feed upon them for at least 20 sec. Such females were essentially unable to forage within host plants and had a low propensity to lay eggs either minutes after or a day after exposure to spheres. Nearly 50% died within 24 h and 85% died within 48 h of feeding. In contrast, females alighting and feeding for at least 180 sec upon sugar/flour spheres containing the insecticide dimethoate at 1.5% active ingredient in the surface coating of yellow latex paint were not immobilized immediately after feeding and in fact were able to forage within host plants and lay eggs equally as well as females that fed on sugar/flour spheres lacking insecticide. It was only after some undetermined amount

of time (but less than 24 h) following feeding on sugar/flour spheres containing dimethoate that females from such spheres suffered ill effects and a high probability of death.

Even though in the field experiment, imidacloprid-treated spheres offered a significant degree of protection of kumquats against egg-laying by *C. capitata* over 24 h periods, whereas dimethoate-treated spheres did not, research needs to be carried out to determine if imidacloprid-treated spheres have as much residual activity as dimethoate-treated spheres following the weathering action of rainfall and sunlight. In this vein, we did in fact expose imidacloprid-treated, dimethoate-treated and untreated spheres to outdoor weather for 3 weeks following the experiments reported here but found that *C. capitata* females were very reluctant to feed on any of the spheres, even though to human taste, there was ample sugar on the sphere surface. A high proportion of the surface of each exposed sphere was covered with growth of microorganisms, which seemingly acted to deter fly feeding. These factors, along with identification of powerful odors to attract mature *C. capitata* females to yellow spheres (Katsoyannos et al. 1997; Prokopy et al. 1997), will need to be examined further to allow development of yellow sugar/flour spheres for potential direct control of *C. capitata*.

#### ACKNOWLEDGMENTS

We thank Baruch Shasha for making the sugar/flour spheres and Terri Moats for assistance in examining kumquats for eggs. We are grateful to an anonymous reviewer for valuable comments. This work was supported by the Massachusetts Society for Promoting Agriculture.

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