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Improvements in the design and usage of red sticky spheres to control the apple maggot fly (R. pomonella).

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IMPROVEMENTS IN THE DESIGN AND USAGE OF RED STICKY SPHERES TO CONTROL THE APPLE MAGGOT FLY (*R. POMONELLA)*

A Thesis Presented

by

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CHAPTER 1

TRAPPING THE APPLE MAGGOT FLY - AN INTRODUCTION

1.1 Description and Habitat

The apple maggot fly, *Rhagoletis pomonella* (Walsh), is a serious dipteran (Family: Tephritidae) pest of apples in eastern and western North America. *R. pomonella* is native to North America and its original host is hawthorn fruit (*Crataegus sp*.). Approximately 150 years ago, *R. pomonella* shifted its host range to include cultivated apples, a fruit introduced to North America from Europe (Prokopy and Bush 1993). To a lesser extent, apple maggot flies also infest cherries, plums, apricots, and pears.

Adult flies emerge from overwintering puparia beneath host trees beginning in June. Females become sexually mature within ten days and will oviposit eggs individually under the skin of developing fruit. A single female is capable of laying between 300 - 400 eggs over its lifetime. Larvae feed inside fruit, creating damaging tunnels that eventually cause the fruit to fall from the tree. Pupation occurs after larvae exit the fallen fruit and burrow into the soil below the tree (Dean and Chapman 1973).

Current conventional control of *R. pomonella* relies upon 3-4 insecticide sprays during the fly season (Reissig et al. 1982). However, the development of a number of effective apple maggot fly traps has created the opportunity to reduce excessive chemical applications. These traps have become useful in integrated pest management programs as tools for monitoring or controlling fly populations.

1.2 Trap Types

There have been three major trap designs that have been used for *R. pomonella* in commercial orchards. The first of these designs is a yellow panel coated with sticky adhesive. These yellow panels provide a visual stimulus that resembles tree foliage, the place where flies are likely to find food, including protein. Therefore, these traps should be attractive to flies foraging for protein sources to complete reproductive development (Prokopy 1968).

The second major trap design has been a red sphere coated with sticky adhesive. Red spheres visually mimic fruit host stimuli in both shape and dark color and are attractive to flies seeking oviposition or mating sites (Prokopy 1968). Studies have shown that spheres 8 cm in diameter capture the greatest numbers of flies. Unfortunately, a serious drawback of sticky coated spheres is that they require substantial maintenance (including cleaning and retreatment every two weeks) to maintain peak effectiveness (Duan and Prokopy 1992). In response to this concern, an alternate sphere design has been developed in which pesticide (incorporated into red paint) replaces the sticky adhesive as the killing agent. These pesticide treated spheres must be coated with a feeding stimulant (sugar solution) to entice alighting flies to feed and ingest a lethal dose of pesticide. This feeding stimulant, however, is likely to be washed away during periods of rainfall (Duan and Prokopy 1995b).

A third trap design for *R. pomonella* is a combination of the yellow panel and red sphere traps. This trap design (commonly referred to as the Ladd trap) combines two red hemispheres at the center of a yellow panel and has shown promise with *R. pomonella* in a number of studies (Kring 1970, AliNiazee et al. 1987, Jones and Davis 1989).

1.3 Odor Lures

There are two types of volatile odor baits that have been used with traps for *R. pomonella*. These lures are either "food" type baits that emit volatiles characteristic of protein food sources or "fruit" type odors consisting of attractive host fruit volatiles. Regarding "food" type odors, compounds containing ammonia have long been known to be attractive to flies (Hodson 1943, 1948). Food odors (ammonium acetate and soy hydrolysate) are commonly used with yellow panel traps to create a trap with visual and chemical stimulus attractive to food seeking *R. pomonella*. With red spheres, protein odor usage has been less frequent. Studies by Prokopy (1968) and Moore (1969) in unmanaged orchards found that spheres baited with ammonium acetate generally increased fly captures over unbaited spheres although the results were somewhat inconclusive.

In terms of fruit odor, Prokopy et al. (1973) observed that the odor of mature apples was attractive to foraging *R. pomonella*. In subsequent work, an attractive mixture of seven volatile compounds was identified and isolated from Red Delicious and Red Astrachan apples (Fein et al. 1982). Red sphere traps baited with this mixture (termed the Fein blend) have been shown to capture significantly more flies than unbaited spheres (Reissig et al. 1985). Later, the Fein blend was refined to a single component, butyl hexanoate, which was shown to be as attractive as the entire blend (Averill et al. 1988).

In a recent study, Duan and Prokopy (1992) combined both fruit (butyl hexanoate) and food (ammonium carbonate) odors with red sphere traps. The combination of odors captured more flies than either odor type alone, although the study was limited in its scope. In chapter two, the optimal usage of food and fruit odor with red sphere traps is further investigated.

1.4 Trap Usage

In orchards, *R. pomonella* traps have functioned as tools for monitoring fly populations and as agents for direct control of fly numbers.

1.4.1 Monitoring *R. pomonella* Populations

Both yellow panel traps and red spheres have been used to monitor *R. pomonella* in the United States. In the eastern states, sticky coated red spheres have been primarily used for this purpose. Pesticide treatment thresholds have been established as two fly captures per trap for unbaited spheres and 5 fly captures per trap for volatile-baited spheres (Stanley et al. 1987; Agnello et al. 1990). In the western states, the Ladd trap (a combination of a yellow panel and red sphere traps) baited with synthetic fruit odor has been shown to outperform red spheres and yellow panels as a monitoring trap in commercial orchards (AliNiazee et al. 1987). Other comparisons of red spheres and yellow panels in western states have been inconclusive as to which is superior for monitoring *R. pomonella*. Host habitat, fly density, and fly maturity may all play a role in the efficacy of each type of monitoring trap (AliNiazee 1990).

1.4.2 Control of *R. pomonella* with Traps

Research has shown that sticky coated red spheres can successfully trap out *R. pomonella* in orchards. In smaller orchards, the deployment of at least one unbaited sticky sphere per tree has been used to effectively control fly populations (Prokopy 1975, 1991; Reissig et al. 1984, 1985). Recent studies in larger orchards have demonstrated that sticky red spheres baited with butyl hexanoate and deployed 5 m apart on the perimeter of an orchard efficiently intercept migrating flies and prevent fruit injury (Prokopy et al. 1990a, Prokopy and Mason 1996). Chapter three further investigates optimal trap deployment strategies for red spheres within an orchard.

While red spheres have proven to be an effective fly control agent, they are impractical for most growers to use, given the cost of maintaining the traps throughout the season. The solution to this problem may lie in the design of a pesticide treated sphere that requires little or no maintenance. At present, however, pesticide treated spheres must be retreated with feeding stimulant (sugar solution) after each rainfall to ensure effectiveness (Duan and Prokopy 1995b). Chapter four discusses an alternative trap design in which pesticide, feeding stimulant, and odor attractants are placed inside perforated spheres to protect against rainfall.

CHAPTER 2

EVALUATION OF ODOR LURES FOR USE WITH RED STICKY SPHERES TO TRAP APPLE MAGGOT FLIES

2.1 Introduction

The apple maggot fly, *Rhagoletis pomonella* (Walsh), is an economically significant pest of apples in eastern North America. As a substitute for pesticide applications, sphere traps coated with sticky adhesive have been used to control fly numbers and prevent fruit injury in orchards (Prokopy 1975; MacCollom 1987; Prokopy 1991; Prokopy et al. 1996). In the east, the most successful trap has been an 8 cm red sphere coated with Tangletrap® adhesive (Prokopy 1968; Reissig 1975; Duan and Prokopy 1992). Such spheres, when baited with odor volatiles and deployed at the perimeter of orchards to intercept immigrating flies, have provided a level of protection nearly comparable to pesticide usage (Prokopy et al. 1990; Prokopy and Mason 1996). However, despite some successes and a substantial amount of research on the trapping of *R. pomonella*, there are still gaps in our knowledge regarding optimal odor attractants for red sphere traps.

Both host fruit volatiles (synthetic fruit odor) and proteinaceous food odor have been used as baits for attracting *R. pomonella*. These odor types are associated with different behavioral responses based on the physiological state of the fly. Fruit odor is attractive to *R. pomonella* seeking fruit resources for oviposition and/or mating (Carle et al. 1987), while food odor is attractive to flies seeking a protein source for reproductive development (Hendrichs et al. 1990 a).

Regarding fruit odor, Fein et al. (1982) found that a mix of seven volatile esters from Red Delicious and Red Astrachan apples were attractive to *R. pomonella*. Subsequent work by Reissig et al. (1982, 1985) showed that red spheres baited with this mixture captured significantly more flies than unbaited spheres. One component of this mixture, butyl hexanoate, was later determined to be as attractive as the entire blend (Averill et al. 1988).

Proteinaceous ammonia-based compounds have long been known to be attractive to *R. pomonella* (Hodson 1943, 1948). Ammonia lures have been used extensively in orchards to monitor *R. pomonella* with yellow rectangle traps (Reissig 1974, 1975; AliNiazee et al. 1987; Jones and Davis 1989; Warner and Smith 1989). With red sphere traps for the apple maggot, ammonia use has had more limited success. Prokopy (1968) found that baiting spheres with a mixture of ammonium acetate and protein hydrolysate increased fly captures over unbaited traps in unmanaged trees, although the difference was not significant. Moore (1969) demonstrated in unmanaged orchards that spheres baited with ammonium acetate were superior to unbaited traps earlier in the season, but not so later in the year. This result presumably reflects a behavioral trend of immature *R. pomonella* to seek food sources early in the season, followed by a switch in response to fruit odor as flies and fruit mature later in the season.

Until recently, the combined use of butyl hexanoate and ammonia-based compounds with red sphere traps had not been evaluated. In a study of limited scope, Duan and Prokopy (1992) found that the addition of ammonium carbonate to butyl hexanoate increased fly captures on red spheres over butyl hexanoate alone in a commercial orchard. However, as the authors pointed out, the work was limited to a short time period in a single orchard and required further study to elucidate the effects of ammonium carbonate on sphere trap captures.

Here, experiments were performed to evaluate the power of butyl hexanoate and ammonium carbonate when alone or combined to attract *R. pomonella* to red sphere traps. The response of flies of three physiological states (14-day-old high egg load, 14-day-old no egg load, and 4-day-old no egg load flies) to odor-baited spheres were first tested in an artificial orchard. Odor- baited spheres were then evaluated in several commercial orchards throughout the active season of *R. pomonella* (early July to mid September). These studies allowed for the determination of the types of flies (physiological states) responding to odor attractants and the measurement of any changes in the pattern of trap captures during the growing season.

2.2 Materials And Methods

2.2.1 Odor Lures

All tests were conducted in the summer of 1995. Butyl hexanoate lures were constructed from capped 15 ml polyethylene vials filled with the liquid. The release rate from these vials has been determined to be approximately 500 μg/h (Averill et al. 1988). Ammonium carbonate lures were a "commercial" type (produced by R. Heath, Gainesville, FL). Each lure consisted of a sealed, clear, plastic container with 1.7 g of ammonium carbonate dispensed from a 1.0 mm hole (a plastic flap covered the hole to protect against rainfall). The release rate from these lures was 650 - 700 μg/h. Although these particular ammonia lures are not available for widespread commercial use, they represent a prototype lure that could easily be used by growers.

2.2.2 Artificial Orchard Assays

Ammonium carbonate and butyl hexanoate were first evaluated in an artificial orchard created from potted hawthorn trees (each ~ 2.0 m in height and ~ 1.5 m in canopy diam.). Four patches of nine trees each were positioned approximately 100 m apart in a large (300 x 300 m) open field. Patches were set up with one central tree, an inner ring of four trees (at the cardinal directions) at 3 m from center, and an outer ring of four trees at 6 m from center. On test days, each patch was assigned one of four odor treatments: no odor, butyl hexanoate, ammonium carbonate, or both butyl hexanoate and ammonium carbonate. A single red sphere was placed in each of the four outer trees along with the designated odor lure(s). The spheres were positioned within the trees so that there was no foliage or tree branches within 10 cm. Odor lures were positioned within 10 cm of a sphere, usually on the same branch. The middle trees were left free of lures and traps to serve as a resting point between the central and outer trees. Spheres were 8 cm diam. (obtained from Pest Management Supply Inc., Hadley, MA) and were coated with a layer of Tangletrap® adhesive (Tanglefoot Co., Grand Rapids, MI). For testing, flies of three physiological states were evaluated separately: 14-day-old protein-fed flies, 14-day-old protein-starved flies, and 4-day-old protein-starved flies. Protein-fed flies were fed a diet consisting of sugar and enzymatic yeast hydrolysate in a 3:1 ratio, while protein-starved flies were fed a sugar-only diet. Flies eclosed from pupae that were collected from apple drops the previous year and overwintered in a cold storage room. At the start of test days, ten females (of a single physiological state) were released on the central tree in each patch and allowed to forage for 4 h. To insure that wild or stray flies from another patch would not be included in the data, released flies were painted with colored Liquid Paper® prior to release (each patch was assigned one of four colors). Once each hour and at the end of the test period, spheres were checked and cleaned of captured *R. pomonella*. In addition, flies from each physiological state were set aside for dissection to determine egg load.

2.2.3 Commercial Orchard Assays

The four odor treatments tested above were also evaluated in four commercial orchards in central and western Massachusetts. In each orchard, replicates consisted of four orchard plots, selected for homogeneity in tree size and spacing (in all, eight replicates across the four orchards were used). The plots were located at the corners of larger orchard blocks and encompassed ~ 50 trees. Within each replicate, one of the four odor treatments was assigned at random to each plot. Red spheres and lures were deployed on perimeter trees of each plot at a spacing of 5 m between traps (~ 14 traps per plot). Traps were hung about 1.5 m above ground (depending on tree size) so that there was no fruit or foliage within 20 cm of a trap (but as much as possible outside of 20 cm). Odor lures were placed within 20 cm of the spheres (usually on the same branch). Traps were initially deployed the first week in July and were maintained through mid September. Once every 2 wks, the traps were checked and cleaned of captured *R. pomonella* and other insects. Odor baits were replaced if necessary. During the first three trapping periods, captured females were brought back to the laboratory for dissection to determine egg load and the proportion of sexually mature females (flies with at least one developed egg). Since captured flies desiccated quickly on spheres, dissections were restricted to recently captured females, limiting n values in all cases.

2.2.4 Data Analysis

For both the artificial and commercial orchard experiments, sphere capture data were analyzed with two way analysis of variance in which odor type and replicates were tested as main effects. Replicates consisted of test days in the artificial orchard assay and block pairings in the commercial orchard study. With the commercial orchards, capture data from each trapping period were analyzed separately. Egg load data from dissections of flies captured in commercial orchards were tested with one way analysis of variance. Multiple comparisons were done using the least significant difference (LSD) test criterion. Regression analysis was used to examine ratios (across sampling periods) of captures on butyl hexanoate baited spheres to captures on unbaited spheres. The level of significance for all tests was set at $\alpha < 0.05$. All analyses were carried out with Statistix 4.0 software (Analytical Software 1992).

2.3 Results

2.3.1 Artificial Orchard Assays

In the artificial orchard experiment (Table 2.1), flies of all three tested *R. pomonella* physiological states (14-day-old protein-fed, 14- and 4-day old protein-starved) exhibited the same general response pattern to the odor types tested. With both protein-fed and 14-day-old protein-starved flies, the combination of butyl hexanoate and ammonium carbonate captured significantly more flies than the other treatments (protein fed flies: $F = 6.89$; df = 3, 33; $P < 0.05$; 14-day-old protein-starved flies: $F = 3.90$; df =

3, 33; $P < 0.05$). With all fly types, spheres baited with butyl hexanoate or ammonium carbonate alone captured numerically more *R. pomonella* than unbaited spheres, although the difference was significant only for protein-fed flies responding to ammonium carbonate. There was a significant effect of test days for protein-fed flies ($F = 5.33$; df = 11, 33; $P < 0.05$), indicating that daily weather conditions may influence fly responsiveness to spheres. In general, protein-fed flies were more responsive to the spheres and odor treatments than protein-starved flies (3.1 captures per replicate for 14-day-old protein-fed flies vs. 1.5 and 0.6 respectively, for 14- and 4-day-old protein-starved flies). Dissection analysis of the females tested revealed that protein-fed flies had a higher mean egg load (17.0 per female) than those deprived of protein (0.3 and 0.0 respectively, for 14- and 4-day-old flies).

Table 2.1: Mean egg load and number of released *R. pomonella* females captured on odor-baited or unbaited red spheres in an artificial orchard. Odor treatments are abbreviated: BH = butyl hexanoate; AC = ammonium carbonate. There were 12 replicates per treatment.

R. Pomonella Physiological State	Mean Egg Load (± SEM)	Mean No. Captures Per Replicate (± SEM) [a]			
		No Odor	BH	AC	BH+AC
14-day-old, protein fed	17.0 (2.7)	2.0 (0.5) c	2.9 (0.6) bc	3.2 (0.5) b	4.3 (0.5) a
14-day-old, protein starved	0.3 (0.2)	0.9 (0.3) b	1.3 (0.4) b	1.3 (0.3) b	2.4 (0.4) a
04-day-old, protein starved	0.0 (0.0)	0.3 (0.2) a	0.7 (0.2) a	0.7 (0.3) a	0.8 (0.3) a

[a] Flies of each physiological state were analyzed separately. Values in each row with separate letters are significantly different according to two way analysis of variance and the LSD criterion at the 0.05 level.

2.3.2 Commercial Orchard Assays

In commercial orchards (Table 2.2), spheres baited with butyl hexanoate captured significantly more *R. pomonella* than spheres with no odor or ammonium carbonate alone. This trend was consistent throughout each of the trapping periods when tested by two way analysis of variance (Period 1: $F = 16.31$; Period 2: $F = 20.17$; Period 3: $F = 18.98$; Period 4: $F = 20.46$; Period 5: $F = 29.46$; for all periods: df = 3, 21; $P < 0.05$). Replicates (i.e. block pairings) were not a significant factor in any of the capture periods ($P > 0.05$). *R. pomonella* captures on spheres with ammonium carbonate alone did not differ significantly from unbaited spheres in any of the trapping periods (in most cases they were actually less). Additionally, captures on spheres having both butyl hexanoate and ammonium carbonate were not significantly different from captures on spheres with butyl hexanoate alone during any trapping period. Due to the low response level of flies, treatments with ammonium carbonate were discontinued after the third trapping period. Regression analysis of ratios of captures on butyl hexanoate baited spheres to captures on unbaited spheres over the five sampling periods revealed a progressive decline in ratio values (from 5.8:1 to 4.4:1) as the season progressed ($y = -1.72x + 13.06$). However, the relationship was weak ($R^2 = 0.09$; $P = 0.06$).

The dissection data from captured females (Table 2.3) were complicated by an oversight in which dissections from the first sampling period (Early July) were not separated by odor treatments. However, there was no significant variation among the three sampling periods in terms of the total (summed over all odor treatments) mean eggs per female ($F = 1.53$; df = 2, 190; $P = 0.22$) or percent sexual maturity of females ($F =$

Table 2.2: Mean number of *R. pomonella* flies captured on odor-baited or unbaited red spheres in commercial orchards. Odor treatments are abbreviated: BH = butyl hexanoate; AC = ammonium carbonate. There were 8 replicates per odor treatment.

Trapping Period [b]	Mean No. Captures Per Sphere (± SEM) [a]			
	No Odor	BH	AC	BH+AC
Early July	2.2 (0.8) b	13.1 (2.0) a	1.7 (0.4) b	10.7 (2.3) a
Late July	6.7 (1.5) b	38.5 (5.5) a	5.7 (1.0) b	38.8 (7.8) a
Early August	10.2 (1.3) b	40.6 (3.3) a	6.5 (1.2) b	36.5 (7.1) a
Late August	5.3 (1.1) b	25.1 (4.0) a	------	------
Early September	3.5 (0.8) b	14.6 (1.9) a	------	------

[a] Each trapping period was analyzed separately. Values in each row with different letters are significantly different according to two way analysis of variance and the LSD criterion at the 0.05 level.
[b] For trapping periods, "Early" refers to the first two weeks of the month and "Late" refers to the last two weeks of the month.

0.51; df = 3, 91; P = 0.68). For the other two periods (Late July and Early August), there was no significant difference among treatments in the percentage of trapped sexually mature females (Late July: F = 0.51; df = 3, 91; P = 0.68; Early August: F = 0.84; df = 3, 55; P = 0.48). The mean egg load per female varied significantly only for the no odor treatment in the Late July period (F = 3.08; df = 3, 91; P = 0.03). There was no significant variation for the Early August period (F = 0.33; df = 3, 55; P = 0.80).

Table 2.3: Mean egg load and sexual maturity of *R. pomonella* flies captured on odor-baited or unbaited red spheres in commercial orchards. Odor treatments are abbreviated: BH = butyl hexanoate; AC = ammonium carbonate.

Trapping Period		Odor Treatment				Average Mean of all odor types [c]
		No Odor	BH	AC	BH+AC	
Early July	Mean eggs/female (± SEM)	---	---	---	---	22.1 (2.2)
	% sexually mature	---	---	---	---	89.5
	N	---	---	---	---	39
Late July	Mean eggs/female (± SEM) [a]	26.9 (2.9) a	17.3 (1.9) b	16.7 (2.0) b	19.1 (2.5) b	19.1 (1.2)
	% sexually mature [b]	100.0	94.4	95.2	95.6	94.7
	N	15	36	21	23	95
Early August	Mean eggs/female (± SEM) [a]	22.5 (2.3) a	20.7 (1.9) a	24.9 (3.5) a	21.3 (2.1) a	22.0 (1.1)
	% sexually mature [b]	100.0	94.7	90.0	100.0	96.6
	N	14	19	10	16	59

[a] For the Late July and Early August trapping periods, values for mean eggs/female with different letters are significantly different according to one way analysis of variance and the least significant difference test criterion at the 0.05 level.

[b] For the Late July and Early August trapping periods, the percent of sexually mature females for each odor treatment was not significantly different according to one way analysis of variance.

[c] For the average mean eggs/female and percent sexually mature females summed over all odor treatments, values were not significantly different among trapping periods according to one way analysis of variance.

2.4 Discussion

Taken together, our findings give two conflicting pictures of the optimal red sphere odor lures for trapping *R. pomonella*. Our initial findings, in the artificial orchard experiment, seemed to confirm those of Duan and Prokopy (1992), in which the use of ammonium carbonate with butyl hexanoate increased red sphere attractiveness to *R. pomonella*. However, our more detailed study in commercial orchards revealed the opposite--that ammonium carbonate had little attractive power relative to butyl hexanoate.

Proteinaceous compounds (such as ammonia) have been shown to be more attractive to immature compared with mature *R. pomonella* (Hodson 1943, Hendrichs et al. 1990 a). Conversely, work by Duan and Prokopy (1994) showed that red spheres baited with butyl hexanoate generally captured more older, mature flies. Therefore, the combination of ammonium carbonate with butyl hexanoate should be attractive to flies of a broad range of age and maturity. Our artificial orchard study (Table 2.1) allowed us to test three separate fly physiological states that might be representative of flies in nature. Interestingly, the pattern of response to the odor types was the same regardless of fly age and maturity. Within the protein fed and protein starved categories, there was an almost equal response to ammonium carbonate or butyl hexanoate alone and a greater response to the combination of the two odors.

Dissections of flies captured in commercial orchards (Table 2.3) revealed that captured females were sexually mature (> 90 %) and of high mean egg load (roughly 20 per female). Odor treatment seemed to make little difference as to the egg load and maturity of trapped females. Unfortunately, our data set was flawed when dissections from the first trapping period (Early July) were mistakenly pooled rather than separated by odor treatment. However, the fact that the mean egg load per female was high (22.1) and a large proportion of captured females was sexually mature (89.5 %) during this period would seem to indicate that mostly high egg load, mature females were being drawn to the spheres even at that early stage of the season. Since fly populations as a whole tend to be more mature later in the season, we expected to encounter a substantial number of immature flies in the earlier trapping periods. The high percentage of mature females captured on the spheres in each trapping period suggests that immature females were not consistently being drawn to the traps at any point in the season. These observations contradict findings by Agnello et al. (1990), who found that both the egg load and maturity of trapped females was lower earlier in the season than later, and Duan and Prokopy (1992), who observed more immature females on spheres with ammonia (52 %) than on spheres with butyl hexanoate (38 %).

Although ammonium carbonate had trapping power comparable to butyl hexanoate in the artificial orchard, it had little or no power in commercial orchards (Table 2.2). In the latter, spheres with ammonium carbonate fared no better than unbaited traps and the addition of ammonium carbonate to butyl hexanoate did not increase *R. pomonella* captures over butyl hexanoate alone.

Despite the results of this study, food odor use with traps has proven to be of definite value in commercial orchards for monitoring other tephritid pests, including the Queensland fruit fly, *Dacus tryoni* (Frogatt) (Bateman and Morton 1981), Caribbean fruit fly, *Anastrepha suspensa* (Loew) (Heath et al. 1993), and the Mediterranean fruit fly, *Ceratitis capitata* (Wiedman) (Heath and Epsky 1995). Studies with perforated sphere traps and the Mediterranean fruit fly have shown that food odor (Nulure) increased fly captures three-fold over unbaited spheres (Katsoyannos and Hendrichs 1995). The reason for the discrepancy between findings in the commercial and artificial orchard experiments here, the findings of Duan and Prokopy (1992), and work with other tephritid species is not altogether clear, although there are three possible explanations.

The first has to do with the design of the lure itself. Studies of protein lures for *R. pomonella* have shown that lure and dispenser type can have an impact on both performance and longevity in the field (Jones 1988). Unfortunately, the ammonium carbonate lures used here did not fare well under hot humid field conditions common to Massachusetts orchards in summer. Typically, the ammonium carbonate within the lure dissipated quickly, sometimes before the end of a two week trapping period. By contrast, lures (of the same design) used in the artificial orchard experiment, when not in use, were stored indoors and were replaced at the first sign of depletion. Duan and Prokopy (1992) experienced a similar problem with ammonium carbonate lure dissipation, but were able to replace the lures frequently (every three days).

Another possible explanation is that there may have been a large amount of food naturally occurring in the commercial orchards studied here, sufficient to overcome the attractive power of ammonium carbonate lures. *R. pomonella* commonly feed on bird feces, honeydew, and diffuse food sources on foliage and fruit, all of which can be abundant in orchards (Hendrichs and Prokopy 1990; Hendrichs et al. 1990 b). These food sources were absent from the potted trees used in the artificial orchard. Along these lines, Prokopy et al. (1993) showed that abundant orchard food sources may interfere with the effectiveness of proteinaceous bait sprays for *R. pomonella*. The impact of naturally occurring food on ammonium-baited spheres is unclear, although there is speculation that these lures will perform better in the absence of natural food (Hendrichs et al. 1990 a).

A third possible explanation involves the distance range of effectiveness of ammonium carbonate lures. To date, there have been no studies evaluating the distance of response of *R. pomonella* to food odor volatiles. It may be that at shorter distances, such as those in our artificial orchard experiment, ammonia has the power to draw flies to spheres, but does not do so at longer distances (such as those in commercial orchards). In the study by Duan and Prokopy (1992), it was suggested that the majority of flies in the test orchard originated from pupae beneath the host trees. This meant that those flies were already in the vicinity of the ammonium carbonate lures upon eclosion and did not have to be pulled to the traps from a significant distance (e.g. 20 m or more). In our study here, by contrast, the majority of flies most likely immigrated from outside the orchard (all unmanaged host trees within 100 m of the orchard perimeter were removed), creating a situation where fly distance from odor source may have been an important factor in lure efficacy.

While ammonium carbonate as a lure with red spheres under Massachusetts apple commercial orchard conditions proved ineffective, butyl hexanoate as a lure with red spheres was indeed successful. Perhaps the most encouraging result from the work reported here was the relative consistency in performance of butyl hexanoate-baited spheres throughout the growing season. There has been some concern that as the season progresses, the increasing amount of natural attractive odor emanating from ripening fruit may compete with butyl hexanoate lures (Carle et al. 1987). In our experiment, the ratio of captures on butyl hexanoate baited versus unbaited spheres dropped slightly from 5.8:1 over the first two trapping periods to 4.4:1 over the last two periods. However, this decline over time was not significant according to regression analysis. Even at its lowest point, the butyl hexanoate/no odor capture ratio achieved here compares favorably with previous findings (Reissig et al. 1985), in which the difference between spheres baited with a blend of synthetic apple volatiles and unbaited spheres was 2 - 4 fold.

Based on the consistent performance of butyl hexanoate throughout the season, it would seem possible for growers using red sphere traps to forgo ammonium lures altogether and still maintain a high level of fly captures. Such a step could reduce the cost of deploying these types of traps, which could be an advantage to their more widespread usage. However, further work will be needed to verify the findings in commercial orchards reported here (particularly the value of ammonium lures). In practice, trapping for pest control involves two major aspects: capturing the target pests and preventing crop injury. Due to time and labor constraints, fruit injury was not evaluated here. Nevertheless, to gain a more complete understanding of the impact of odor lures on red sphere traps, the question of fruit injury ought to be addressed in a future study.

CHAPTER 3

EVALUATION OF TWO TRAP DEPLOYMENT METHODS TO MANAGE THE APPLE MAGGOT FLY

3.1 Introduction

The apple maggot fly, *Rhagoletis pomonella* (Walsh), is a major summer pest of apples in eastern North America. Infestations in apple orchards typically occur from flies immigrating from nearby unmanaged host trees outside the orchard. In some cases, however, they occur from flies arising within the orchard from infested dropped fruit of the previous year. In response to concerns over pesticide applications, some recent control efforts have focused on the use of red sphere traps coated with sticky adhesive to reduce fly numbers and prevent fruit damage. Studies in small orchards have shown that sphere traps deployed at the rate of at least one per tree throughout the orchard are capable of effectively suppressing flies (Prokopy 1975, 1991; Reissig et al. 1984, 1985). Unfortunately, a trapping scheme of one trap per tree is not practical in larger orchards, given the cost of purchasing and maintaining sphere traps.

To minimize the number of traps needed for control of *R. pomonella*, it may be useful to view the deployment of red spheres in an apple orchard as a trap cropping system. Trap crops, which can be of the same or different cultivar as the main crop, are designed to attract and concentrate pests is a small portion of the crop where they can be eliminated (Hokkanen 1991). In apple orchards this could be accomplished by drawing flies with odor lures to trees containing red sphere traps. The location of trees containing traps in orchard blocks ideally should be based upon the expected source of infestation, whether it is from immigrating flies or flies emerging from within the orchard.

Regarding infestation from immigrating flies, research has shown that barriers of sphere traps baited with synthetic fruit odor (butyl hexanoate) spaced 5 m apart and deployed on perimeter trees of commercial orchards effectively intercepted incoming flies (Prokopy et al. 1990 a; Prokopy and Mason 1996). While this method has proven quite successful in practice, some of the dynamics of the system are not fully understood. For example, it is not clear to what extent this method provides protection, since the experiments were not run with a no-trap control (a treatment not feasible in commercial orchards).

Infestation resulting from within-orchard emergence of *R. pomonella* presents a complex situation. This type of infestation can arise if flies are able to penetrate perimeter traps and oviposit on interior trees of the orchard. In such cases, the following year flies will emerge from directly beneath orchard trees in the immediate vicinity of host fruit and possibly a substantial distance from odor-baited spheres on perimeter trees. These flies may pale in number relative to immigrating *R. pomonella*, but considering the high egg load of a typical fly (a single female can lay 300 eggs over its lifetime; Dean and Chapman 1973), the predicament can be considerable. Presently, the only reliable method to deal with this sort of problem is to regularly remove apple drops as they fall, a laborious and impractical procedure for most growers (Hu et al. 1996). There is also indication that the withdrawal of daminozide (Alar) from use in orchards as a treatment to prevent fruit from falling prior to ripening has contributed to the problem by permitting excessive apple drop (Prokopy et al. 1990 b).

To combat within-orchard emergence of *R. pomonella*, one can envision the deployment of odor-baited red spheres on a number of trees at the interior of the orchard, which would serve as trap trees to draw and concentrate flies foraging inside the orchard. The key to the success of this method hinges upon the ability of odor lures to pull flies from trees containing fruit resources to trees containing spheres before significant oviposition is initiated. This method is analogous to a trap crop positioned at the interior of a field. Along these lines, a trap tree scheme has been proposed for *Anastrepha* fruit flies in Mexico, in which favored native host mango trees that are more attractive than commercial mangos could be planted within an orchard to draw and concentrate flies (Aluja and Liedo 1986). However, to my knowledge, this type of practice has not yet been attempted for control of *R. pomonella* and protection of apple fruit.

Here, I separately evaluated both a barrier (perimeter) and trap tree (orchard interior) sphere deployment strategy by using similar trapping schemes in artificial orchards (patches of potted hawthorn trees). The use of potted tree patches allowed for the manipulation of variables not possible to evaluate in commercial orchards, such as a no-trap control and different fruit types. Each method was tested with two separate hosts: hawthorn (the high-ranking native host of *R. pomonella*) and apple (an intermediate-ranking host) with released female flies of high egg load.

3.2 Materials and Methods

All tests were carried out during the summers of 1994 and 1995. All flies used were females and of wild origin, having emerged from puparia collected from apple drops the previous summer. Flies were fed a diet of sugar and enzymatic yeast hydrolysate (3:1 ratio) until testing at an age of 18-22 days. Allowing test flies to feed on a diet of protein insured that most females would be sexually mature and possess a high egg load. In commercial orchards, it is flies of this type that have the greatest potential for causing fruit injury. The traps used in the experiments were 8 cm red spheres (Pest Management Supply Co., Hadley, MA) coated with Tangletrap™ adhesive (Tanglefoot Co., Grand Rapids, MI). Odor lures for the spheres consisted of butyl hexanoate (synthetic fruit odor, dispensed from capped 15 ml polyethylene vials) and ammonium carbonate (food odor, dispensed from plastic lures produced by R. Heath, Gainesville, FL). The release rates of the lures were approximately 500 μg/h for butyl hexanoate (Averill et al. 1988) and 650-700 μg/h for ammonium carbonate. Test fruit were either ripe, uninfested hawthorns (collected from a wild tree covered the previous summer and stored at 3° C until use) or young Gravenstein apples (obtained in late June from a local orchard). Hawthorns are the preferred (native) *R. pomonella* host, while apples are typically a lower ranking host (Prokopy et al. 1985).

For simplification, the perimeter trapping scheme was termed the "barrier" method, since the objective was to create a barrier to prevent immigrating flies from reaching fruit resources. The within-orchard trapping scheme was designated the "pull" method, as the goal was to pull flies away from fruit resources they may have already encountered. Using patches of potted trees, it was possible to arrange trapping schemes of this sort for both the barrier and pull methods.

Three patches of nine hawthorn trees each were set up 100 m apart in a large, open, mowed field (300 x 300 m). Each tree was fruitless, with an approximate height of 2 m and a canopy of 1.5 m. Patches were arranged with one central tree, an inner ring of four trees at 4 m from center (at the cardinal directions), and an outer ring of four trees at

6 m from center (at the cardinal directions). The central tree served as the release point for test flies, while the other trees housed either spheres or test fruit.

For the "barrier" scheme, patches were set up with red sphere traps on the inner ring of trees and test fruit on the outer ring. Spheres were deployed one per tree (a total of four per patch) and were hung so as to maximize the amount of foliage nearby a trap (but no closer than 10 cm). When required, each sphere was baited with four lures containing butyl hexanoate and four lures containing ammonium carbonate (four lures were used to insure a high amount of odor in the patches), each of which was placed within 10 cm of a trap. On each of the outer trees, five fruit (either hawthorns or apples) were evenly spaced throughout the tree (attached by copper wire). This design was analogous to a perimeter trapping scheme in a commercial orchard in that flies (released from the center tree) had first to penetrate trees with traps (the inner ring of trees) before reaching host fruit on the outer trees.

For the "pull" scheme, patches were set up as above except that all spheres were placed on outer trees while all fruit were placed on inner trees. This created a situation where flies would be drawn through trees containing fruit before reaching trees with traps.

For both the "barrier" and "pull" experiments, there were three treatments: odor-baited traps, unbaited traps, and no traps. The no-trap treatment was used as a baseline to determine the level of oviposition in the absence of any control measures. On a given test day, the three patches were assigned at random to the three "barrier" treatments or the three "pull" treatments, with only a single host type evaluated per test day. Prior to testing, flies were color-coded according to patch type using colored Liquid Paper® to guarantee that no wild or stray flies would be included in the capture data set. At the start of each assay, twenty females were released in each patch on the center tree. Inspections of the spheres for captured flies were made hourly. After six hours, spheres were removed and test fruit were brought back to the laboratory. The number of eggs laid was determined from dissections of test fruit using a microscope. Periodically, test flies were dissected to determine egg load.

Sphere capture and fruit dissection data were analyzed by two way analysis of variance in which columns consisted of treatments (odor-baited spheres, unbaited spheres, and no-trap patches) and rows consisted of replicates (test days). Where ANOVA indicated significant differences existed, means were separated by the least significant difference test criterion ($\alpha = 0.05$). All analyses were carried out with Statistix 4.0 software (Analytical Software 1992).

3.3 Results

3.3.1 Perimeter Trapping Scheme

With the "barrier" strategy (Table 3.1), amount of oviposition was significantly reduced in hawthorns (over the no trap control treatment) through the use of baited or unbaited red sphere traps ($F = 5.08$, df = 2, 23, $P < 0.05$). The difference amounted to a 62-63 % reduction in the number of eggs laid compared with numbers laid in patches without traps. Odor-baited red spheres (but not unbaited spheres) reduced oviposition in apples (by 100 %), although the difference was not significant due to higher variance. For both hawthorns and apples, odor-baited spheres captured significantly more flies than unbaited spheres (hawthorns: $F = 18.71$, df = 1, 23, $P < 0.05$; apples: $F = 9.46$, df = 1, 23, $P < 0.05$).

3.3.2 Within-Orchard Trapping Scheme

For the "pull" strategy (Table 3.1), odor-baited spheres significantly reduced oviposition (by 76 %) in hawthorns over the no trap control treatment ($F = 5.71$, df = 2, 23, $P < 0.05$). Unbaited traps also reduced the number of eggs found (by 33 %), although the difference was not significant from the no-trap treatment. With apples, oviposition was reduced by both odor-baited (70 %) and unbaited spheres (96 %), but not

Table 3.1. Number of released *R. pomonella* flies captured and amount of egglaying (oviposition) in tree patches where "barrier" and "pull" trapping schemes were deployed. There were 12 replicates per treatment.

	BARRIER SCHEME		PULL SCHEME	
Fruit/Treatment	Mean captures per replicate (± SEM)[a]	Mean eggs laid per replicate (± SEM)[a]	Mean captures per replicate (± SEM)[a]	Mean eggs laid per replicate (± SEM)[a]
Hawthorn				
--Baited Traps	11.2 (0.8) a	3.7 (1.6) b	8.8 (1.0) a	3.6 (1.3) b
--Unbaited Traps	7.3 (0.9) b	3.8 (1.6) b	6.1 (0.7) b	10.0 (3.1) ab
--No Traps	----	10.1 (1.6) a	----	14.9 (2.4) a
Apple				
--Baited Traps	10.5 (1.1) a	0.0 (0.0) a	8.3 (1.0) a	0.7 (0.4) a
--Unbaited Traps	7.0 (1.1) b	2.4 (1.5) a	6.0 (1.0) a	0.1 (0.1) a
--No Traps	----	2.5 (1.3) a	----	2.3 (1.2) a

[a] For each trapping method, captures and ovipositions were analyzed by two-way analysis of variance. Values for each fruit type in each column with separate letters are significantly different by the least significant difference test at the 0.05 level.

significantly ($P > 0.05$). Sphere captures were numerically greater on baited traps than on unbaited traps for both hawthorns and apples, although the difference was significant only for hawthorns ($F = 8.89$, df = 1, 23, $P < 0.05$).

Two way analysis of variance for the fly capture and oviposition data in both the "pull" and "barrier" experiments revealed that there was no significant effect of replicates (test days) on sphere captures or egg laying ($P > 0.05$). Dissections of test flies revealed an average egg load of 23.4 (± 2.8) per female, which did not vary among treatments.

3.4 Discussion

Based on the results of this study, both the perimeter ("barrier") and within orchard ("pull") trapping methods tested here would seem to have potential for managing *R. pomonella*. With both methods, the use of odor-baited red spheres significantly reduced oviposition in hawthorns over a no-trap situation. A similar reduction in the number of eggs laid was also observed with apples, although *R. pomonella* oviposition in apples was too variable (even in the no-trap treatment) to be statistically significant.

The work here with potted trees allowed us to manipulate variables that would normally be impractical to alter in a commercial orchard. By using released flies of wild origin, it was possible to test exclusively high-egg-load females, which represent flies with the most potential to damage fruit in nature. It was also feasible to use hawthorns as a test fruit, which are a favored *R. pomonella* host and are analogous to the most susceptible cultivar of apple a grower could have in an orchard. Given these "worst case" scenarios tested here, the positive effects of the trap deployment methods evaluated were encouraging, in terms of both capturing flies and preventing oviposition.

The use of a barrier on the perimeter of a field to intercept immigrating pests is central to using a trap crop approach to pest management. Trap crops, baited with the pheromone grandlure and deployed at the edge of a field, have shown promise as a management tool for the cotton boll weevil, *Anthonomus grandis* Boheman (Dickerson 1986). In cauliflower, the rape blossom beetle, *Meligethes aenus* F., has been successfully controlled with trap crops that form a barrier between the field and the source of infestation (Hokkanen et al. 1986). Other recent studies have demonstrated the effectiveness of using perimeter trap crops for controlling the olive beetle, *Phloeotribus scarabaeoides* (Bern.) (Gonzalez and Campos 1995), and the red sunflower weevil, *Smicronyx fulvus* LeConte (Brewer and Schmidt 1995). With some of these pests (cotton boll weevil, olive beetle), the use of odor attractants and pheromones has served to increase the effectiveness of trap crops. These pest insects share much in common with *R. pomonella* in that they are highly mobile and usually originate from sites away from target crops.

With *R. pomonella*, research has demonstrated the effectiveness of odor-baited perimeter traps at reducing insecticide applications while maintaining an acceptable level of fruit injury (Prokopy et al. 1990; Prokopy and Mason 1996). However, due to the constraints associated with experiments conducted in commercial orchards, such efforts did not directly test the efficacy of perimeter traps against a no-trap treatment. The data obtained in this study seem to support the benefits of barrier traps observed in commercial orchards, demonstrating that with high egg load flies and a very susceptible host fruit (hawthorn), it is still possible to significantly reduce fruit injury. These advantages were also observed with apples, a lower ranking host, although not significantly in the experiments reported here.

Within-orchard emergence of *R. pomonella* presents a greater dilemma for pest management. Flies emerge in close proximity to fruit resources and must be pulled away to traps before inflicting serious damage. Here, the data suggest that this may be possible. The large reduction (76 %) of oviposition in hawthorns is indicative that odor lures were able to draw flies through trees containing favored fruit hosts to red sphere traps. This type of trap deployment within an orchard is comparable to a trap cropping situation in which pests arrive at a field early in the season, before the crop is vulnerable to infestation. In these cases, pests are not concentrated in trap crops on the perimeter (since they are not yet attractive), but rather disperse throughout the field. The placement of trap crops within the field becomes necessary, once the crop becomes attractive and vulnerable (Hokkanen 1991).

Another analogous scenario to the "pull" method evaluated here has been tested with the mountain pine beetle, *Dendroctonus ponderosae* Hopkins. There, it was demonstrated that trees in the center of a forest stand baited with attractive semiochemicals were able to concentrate beetles and prevent tree damage to surrounding areas of the stand (Gray and Borden 1989). Indeed, trap trees have been a common approach to managing many species of bark beetles (Bakke and Lie 1989).

An important factor to consider in these experiments is the amount of odor used with each trap. Four odor lures each of butyl hexanoate and ammonium carbonate were used, a high amount of each type. By using this large amount, it was hoped that the trap trees would be made "super attractive," surpassing the attractiveness of trees containing fruit. A similar approach has been envisioned for orchards, with a small number of optimally selected trees on the interior containing one or more traps in company with multiple odor baits to increase trap power. However, the use of multiple odor lures would increase the cost of deploying sphere traps.

When one considers the structural differences between commercial orchards and the "artificial orchard" tree patches used here, it becomes clear that the extrapolation of findings here into real-world orchards for the purpose of predicting the precise efficacy of the two trapping methods is inadvisable. Rather, this research demonstrates the relative effectiveness of each method for preventing oviposition and the potential each has for use in commercial orchards. Ideally, future studies will compare these methods in orchards. However, this will prove difficult because growers are reluctant to tolerate unsprayed patches of trees without traps.

CHAPTER 4

APPLE MAGGOT FLY RESPONSE TO PERFORATED RED SPHERES

4.1 Introduction

The apple maggot, *Rhagoletis pomonella* (Walsh), is a major pest of apples in eastern and central North America. Recently, odor-baited sticky traps have been used as a substitute for pesticide in controlling apple maggot in several commercial orchards (MacCollom 1987, Prokopy et al. 1990a). To date, the most economically effective trap has proven to be an 8 cm red sphere coated with Tangletrap® adhesive and baited with synthetic food and/or fruit odor (Duan & Prokopy 1992). One of the impediments to greater use of such spheres by apple growers is the laborious process of coating the spheres with a sticky adhesive and cleaning them of insects and debris every two weeks to maintain capturing effectiveness (Duan & Prokopy 1995b).

In concept, pesticide applied to spheres could be an effective substitute for adhesive in killing *R. pomonella*. Toward this end, Duan & Prokopy (1995a) showed that spheres coated with a mixture containing dimethoate, sucrose as a feeding stimulant eliciting fly ingestion of pesticide, and latex paint as a residue-extending agent killed a large majority of alighting *R. pomonella* before exposure to rainfall. After rainfall, however, the spheres were less effective, largely due to loss of feeding stimulant. An analogous trap for the olive fruit fly, *Dacus oleae* (Gmelin), consisting of a plywood rectangle soaked in deltamethrin and sucrose, provided effective control in Greece (Haniotakis et al. 1991). However, no rain fell during the trapping period due to the dry climate.

There have been two principal approaches to eliminating the negative effects of rainfall on the residual activity of pesticide and feeding stimulant: (1) using a protective cover to prevent rainfall from contacting the spheres, and (2) finding a more effective residue-extending polymer to combine with or substitute for latex paint (Prokopy et al. 1995). Regarding the former, to date all tested variants of protective covers placed above spheres have been found to reduce alightings of *R. pomonella* by at least 50 percent, an unacceptable level (Duan & Prokopy 1992). A possible alternative to a protective cover is the placement of pesticide, feeding stimulant, and synthetic food and fruit odor within a hollow, perforated sphere. The wall of the sphere would serve to protect the interior from rainfall. A similar perforated, cylindrical trap baited with food odor is being developed for the Mediterranean fruit fly, *Ceratitis capitata* (Weidmann) (Health & Epsky 1995). However, to my knowledge, spheres of this type have not yet been evaluated against *R. pomonella* or any other tephritid flies. Previously, Reissig (1974, 1975) evaluated a yellow hollow rectangular box with a hole on each side and food odor and pesticide on the interior as a potential trap for *R. pomonella*. Initially, it appeared to be an effective trap in trees harboring hungry adults, but subsequently it proved ineffective when evaluated under a broader range of field conditions.

Here, I first evaluated *R. pomonella* response to internally and externally-baited red spheres perforated with holes and to internally-baited spheres with varying numbers of holes. Post-alighting behavior was then observed on internally-baited spheres with varying numbers of holes. Finally, I evaluated commercially available red sphere traps designed so that both feeding attractant and pesticide are contained in a liquid inside the trap and are released through a sponge on the underside of the sphere, protected from rainfall.

4.2 Materials and Methods

4.2.1 Internally Versus Externally-Baited Spheres

In the first experiment, internally and externally-baited red spheres were evaluated for propensity to capture *R. pomonella* in a commercial orchard. The spheres (obtained from Pest Management Supply Co., Hadley, MA) consisted of two separate, hollow halves (10 cm diam.), which allowed odor baits to be placed inside the trap. Odor baits consisted of one unit each of synthetic fruit odor (butyl hexanoate, dispensed from a capped 15 ml polyethylene vial) and synthetic food odor (ammonium carbonate packet, purchased from R. Heath, Gainesville, FL). Spheres were perforated with three 2.4 cm holes. Four treatments were set up: (1) internally-baited spheres with two cardboard strips containing dimethoate (also placed inside) as the killing agent, (2) internally-baited spheres coated with a layer of Tangletrap® (from the Tanglefoot Co., Grand Rapids, MI), (3) externally-baited spheres (odors placed about 10 cm from the traps) with Tangletrap, and (4) externally-baited, non-perforated spheres with Tangletrap. The test was conducted in an orchard block of about 30 Gravenstein apple trees. Traps were positioned, one per tree according to methods described by Duan & Prokopy (1992). After one week, captured flies were counted and removed, and the trap types were rotated. Capture data were analyzed using a two way ANOVA, in which columns consisted of trap type and rows consisted of replicates.

4.2.2 Perforated Spheres with a Variable Number of Openings

In the second experiment, sticky 0-, 3-, 6-, 12-, and 24-hole spheres were evaluated for propensity to capture *R. pomonella*. Holes were 2.4 cm diam. except for the 24-hole spheres, which were 1.4 cm. The odor baits used in this test were the same as in the first experiment. All traps were coated with Tangletrap and internally-baited (except for the 0-hole sphere, which was externally-baited). One trap of each type was hung in a large hawthorn tree known to contain a substantial *R. pomonella* population. Once daily, the traps were checked for *R. pomonella* captures, cleaned, and rotated. This was done for one complete rotation (5 days). For each day, the total number of fly captures over all trap types was summed and a percentage of that total was then calculated for each trap type. By using this approach, any day-to-day fluctuations in *R. pomonella* population size and activity were negated. Data were analyzed using a two way ANOVA, in which columns consisted of trap type and rows consisted of test days (trap position).

4.2.3 Post-Alighting Behavior on Perforated Spheres

In the third experiment, post-alighting behavior of *R. pomonella* was observed on internally baited, red spheres with 3, 6, 12, or 24 holes. We wanted to determine fly inclination to enter holes to the interior of the trap (where feeding stimulant and pesticide could potentially be located). The same hawthorn tree and traps used in the second experiment were used in this test. Three traps of each type were hung and monitored for *R. pomonella* alightment, flies entering trap holes and time spent on the sphere. Residence times of *R. pomonella* on the spheres were analyzed by a one way ANOVA.

4.2.4 Post-Alighting Behavior on Fruitect Spheres

In the fourth experiment, an alternative trap type (Fruitect trap, mfd. by RonPal Ltd., Rishpon, Israel) and red wooden spheres were evaluated for *R. pomonella* post-alighting behavior. The Fruitect trap consisted of a red plastic sphere (12.5 cm diam.) in which a feeding attractant (protein hydrolysate) and feeding stimulant (sucrose) were dispensed from the interior to the exterior via a sponge that formed a 1.0 cm band on the underside of the sphere. Red wooden spheres (8.0 cm diam.) were dipped in an aqueous solution of 20% sugar prior to testing. The test was conducted in an indoor field cage by hanging four spheres (Fruitect and wooden spheres were tested separately) in a potted fig tree. For each trial, 40 female *R. pomonella* were released and allowed to forage freely for up to 1 h. Test flies were of wild origin, aged 3-4 weeks, and were either starved of all protein or continually fed protein since eclosion. Alighting flies were monitored for total time on the sphere and time spent feeding. Data on residence time, percent feeding, and feeding time were analyzed using two sample t-tests.

4.3 Results

4.3.1 Internally Versus Externally-Baited Spheres

In Experiment 1 (Table 4.1), approximately 30-40 % fewer *R. pomonella* were caught on 3-hole sticky traps internally-baited than on externally-baited sticky traps with or without 3 holes. Internally-baited 3-hole traps with pesticide instead of Tangletrap® as the killing agent failed to trap a single fly over the entire experiment.

4.3.2 Perforated Spheres with a Variable Number of Openings

In Experiment 2 (Table 4.2), externally-baited traps with no holes captured the highest number of flies and had the highest daily percentage of fly captures. Daily percent fly captures were about 15-40 % less on the internally-baited spheres, although two way ANOVA showed that differences among all five trap types were not significant.

4.3.3 Post-Alighting Behavior on Perforated Spheres

In Experiment 3 (Table 4.3), 0, 0, 0 and 16 % of alighting flies, respectively, entered holes in 3-, 6-, 12-, and 24-hole spheres. Flies spent more time on 3- (significant) and 24-hole spheres than on 6- and 12-hole spheres.

4.3.4 Post-Alighting Behavior on Fruitect Spheres

In Experiment 4 (Table 4.4), a significantly greater proportion of alighting flies fed on red wooden spheres than on Fruitect traps. This was true for protein-fed flies (90 vs. 2 %) and protein-starved flies (75 vs. 23 %). Protein-fed flies on red wooden spheres fed much longer than flies on Fruitect traps (although the sample size feeding on Fruitect traps consisted of only one fly). Protein-starved flies on Fruitect and red wooden spheres showed no significant difference in mean time feeding.

4.4 Discussion

Our findings indicate that the trap designs tested here are not an effective alternative to prototype pesticide-coated spheres described by Duan & Prokopy (1995a). To kill *R. pomonella* alighting on a sphere using pesticide instead of Tangletrap®, flies must remain on the sphere long enough to acquire a lethal dose of toxicant. This is best accomplished when toxicant is combined with a feeding stimulant (such as sucrose) and a high percentage of alighting flies contacts the pesticide/sucrose mixture (Duan & Prokopy 1995a). The trap designs tested here failed in this regard.

The perforated hollow red spheres were constructed to protect both feeding stimulant and pesticide from rainfall by encasing them within the sphere. Success, however, is contingent upon the notion that alighting *R. pomonella* will readily enter trap holes to gain access to feeding stimulant and pesticide. This did not prove to be the case. In Experiment 3, only a very small percentage (no more than 16%) of flies alighting on perforated spheres actually entered a hole, regardless of the number of holes per sphere. Clearly, this is inadequate, as the vast majority of flies alighting on spheres will never come into contact with the killing agent. Reluctance to enter openings into traps has been shown in other tephritid flies as well. Reissig (1976) showed that with the cherry fruit flies *Rhagoletis fausta* (Osten Sacken) and *R. cingulata* (Loew), traps requiring the flies to enter constricted openings were not effective. Prokopy & Economopoulos (1975) showed that non-sticky McPhail traps (which require flies to enter a port for capture) captured less than half of arriving olive flies. Similarly, Aluja et al. (1989) found that only 31 % of *Anastrepha* spp. flies alighting on McPhail traps were ultimately captured. However, tests have shown that perforated cylindrical traps baited internally with food odor have promise for capturing both female and male Mediterranean fruit flies, although the percent of alighting flies that ultimately are captured is unknown (Heath & Epsky 1995). The reason why most *R. pomonella* in this study and most tephritid flies in other studies were not inclined to enter holes in traps containing bait on the interior is uncertain. Possibly, most alighting flies do not come into contact with plumes of attractive odor emanating from trap holes.

The Fruitect red spheres tested here also failed to elicit a sufficient level of fly feeding to be effective. As was the case with hollow perforated spheres, most *R. pomonella* alighting on Fruitect traps departed without ever contacting the site of feeding stimulant and potential killing agent. The problem with Fruitect spheres may be that the sponge containing the feeding stimulant represents only a small part of the total surface area of the sphere. Conversely, flies that alighted on sucrose-coated red wooden spheres were exposed to feeding stimulant almost immediately upon tarsal contact with the sphere surface.

An additional factor to consider is trap attractiveness to foraging flies. We found in Experiments 1 and 2 that internally-baited red spheres were consistently slightly less attractive to *R. pomonella* than externally-baited spheres. A possible explanation for this is that the amount of odor released may have been reduced by positioning odors inside the sphere as opposed to outside.

To date, three approaches towards the development of a pesticide-treated sphere for controlling *R. pomonella* have been evaluated. The first of these is coating the exterior of the sphere with both feeding stimulant and pesticide. This approach is represented by the 8 cm wooden spheres described by Duan & Prokopy (1995a). These traps have been shown to be as effective as traditional red sticky spheres in managing *R. pomonella* in commercial orchard blocks, with the major drawback being negative effects of rainfall (Duan & Prokopy 1995b). The second and third approaches (tested here) attempted to modify sphere design so that feeding stimulant and pesticide could be protected from rainfall. The second approach places feeding stimulant and pesticide within the trap interior, thus protecting it from rain. The third approach places feeding stimulant on the interior which is dispensed to the surface of the trap through a sponge. Neither of these two designs showed promise as an alternative to the first approach. Future research efforts will be directed at increasing the residual effectiveness of exterior-coated pesticide spheres using residue extending agents.

Table 4.1. Mean number of *R. pomonella* captured per replicate on four red sphere trap treatments. Each treatment was baited with one unit each of butyl hexanoate and ammonium carbonate. There were 12 replicates (n=12).

Trap Type	Killing Agent	Odor Position	Mean No. Flies Captured Per Replicate ± SE [a]
3-hole	Dimethoate	Internal	0.0 ± 0.0c
3-hole	Tangletrap	Internal	24.3 ± 5.8b
3-hole	Tangletrap	External	41.3 ± 7.6a
0-hole	Tangletrap	External	36.1 ± 5.8ab

[a] Column values with different letters are significantly different according to two way ANOVA and LSD criterion at the 0.05 level.

Table 4.2. *R. pomonella* captures on baited red sticky spheres with different numbers of holes. All traps were internally-baited except the 0-hole trap which was externally-baited. Results for each trap type are expressed as the mean percentage of total daily captures for all trap types combined. There was a total of 5 one-day capture periods (n=5).

Trap Type	Total No. Trap Captures	Mean Percent of Total Daily Captures ± SE [a]
0-hole	347	25.9 ± 4.9
3-hole	285	21.4 ± 3.3
6-hole	203	15.1 ± 3.2
12-hole	193	15.3 ± 1.9
24-hole	286	22.3 ± 2.8

[a] Differences in percentage captures between trap types were not significant according to two way ANOVA at the 0.05 level.

Table 4.3. Mean *R. pomonella* residence time and fly propensity to enter holes in red sphere traps with varying numbers of holes. Each trap was internally-baited with one unit each of butyl hexanoate and ammonium carbonate.

Trap Type	No. Flies Alighting	Mean Time Per Fly Spent on Trap ± SE [a]	% Alighting Flies Entering Trap Holes ± SE
Exp. A			
3-hole (pesticide)	36	118.3 ± 30.7a	2.8 ± 2.8
3-hole (no pesticide)	23	163.2 ± 71.4a	0.0 ± 0.0
Exp. B			
6-hole (no pesticide)	25	18.4 ± 3.0b	0.0 ± 0.0
12-hole (no pesticide)	25	38.9 ± 11.2b	0.0 ± 0.0
24-hole (no pesticide)	25	110.2 ± 27.5a	16.3 ± 7.5

[a] Mean times were analyzed separately for Exp. A and B. Exp. A was analyzed by a two sample t-test. Exp. B was analyzed by one way ANOVA. For each experiment, column values with different letters are significantly different at the 0.05 level.

Table 4.4 Mean residence and feeding times of *R. pomonella* on Fruitect and red wooden sphere traps in an indoor field cage study.

Fly type --Trap Type	No. Flies Alighting	Mean Time Per Fly Spent on Trap ± SE [a]	% Feeding ± SE [a]	Mean Feeding Time Per Fly ± SE [a]
Protein Fed				
--Fruitect	51	204.3 ± 41.5a	2.0 ± 2.0b	5.0 ± ---
--Wooden sphere	30	204.8 ± 46.2a	90.0 ± 5.6a	212.0 ± 51.2
Protein Starved				
--Fruitect	52	240.2 ± 27.5a	23.1 ± 5.9b	162.7 ± 35.4a
--Wooden sphere	40	161.5 ± 30.2a	75.0 ± 6.9a	172.0 ± 32.3a

[a] Protein fed and protein hungry flies were analyzed separately. For each fly type, column values with different letters are significantly different according to a two sample t-test at the 0.05 level.

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