Improvement of Sugar-delivery Systems for Rain-activated, Pesticide-treated Spheres

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Introduction

Through use of odor-baited sticky red spheres, effective behavioral control of apple maggot is possible and has been widely reported in *Fruit Notes*. However, the sticky material used to snare alighting apple maggot flies (AMF) is very difficult to handle and requires frequent maintenance. In order to develop trap-based AMF control that is practical for commercial adoption, we have worked for many years toward development of pesticide-treated spheres (PTS) to substitute for inefficient sticky-coated spheres. Although PTS have shown great promise in both laboratory and field trials, the major challenge we face is continuously supplying the sphere surface with enough sugar to stimulate fly feeding, thereby allowing PTS to achieve maximum toxicity to AMF with a minimal dose of insecticide. To date, we have developed two approaches to providing a consistent supply of sucrose to sphere surfaces under field conditions: a reusable wooden PTS with an external source of feeding stimulant and a disposable sugar/flour PTS whose entire body consists of sugar and starches (see *Fruit Notes*, Volume 65).

Data from field and laboratory trials in 2000 strongly suggest that wooden PTS retain toxicity to AMF for at least 12 weeks, while sugar/flour PTS may begin to lose their toxic effects after as little as six weeks of field exposure. From direct observations of fly feeding on PTS and assessments of fly behavior after exposure, it appears that, along with some sugar, some toxicant is lost from the sugar/flour PTS during rainfall. Given this, we believe that further development of re-usable wooden PTS may hold greater long-term promise for commercially viable behavioral control of AMF than do sugar/flour PTS.

Since 1997, we have worked toward development of a wooden PTS system focusing on use of a sucrose-bearing top-cap affixed to each sphere which, under rainfall, releases a small amount of sucrose onto the sphere surface. Thus, as surface sugar is dissipated under rainfall or heavy dew, it is replaced with sucrose from a source atop the PTS. In 1997 and 1998, we attempted to form these caps of nearly pure sucrose, finding quickly that the pure sugar caps were highly prone to breakdown under conditions of high humidity. In 1999, we formed and tested flat-topped, 1 ½” caps consisting of 85% sucrose bound in 15% paraffin (25 grams total mass). Although these caps worked for a short time in the field (~3 weeks), they ran out of sugar well before the close of the season.

In 2000, we again tested caps consisting of 85% sucrose bound in 15% paraffin, but modified the caps in 3 major ways: 1) we increased the diameter to 2 inches; 2) we doubled the mass to 50 grams; and 3) we formed the caps using a hydraulic press that stamped eight flutes into the top of each cap, ensuring even distribution of sucrose-bearing runoff. Upon lab testing, this style of cap was effective through five inches of accumulated rainfall (roughly equal to five weeks of field exposure). This was by far the best-performing wooden PTS to date, but we needed to address two major shortcomings: 1) further modification of caps to ensure effectiveness through at least mid-season (six to eight inches of rainfall), and 2) prevention of rodent damage to caps. From the laboratory-based studies reported here, our goal was to improve the consistency and durability of sugar release from wax/sugar caps for deployment on wooden PTS in 2001.

Materials & Methods

For each of the trials described below, we mounted experimental caps on 3.3-in wooden spheres prior to artificial rainfall exposure. Sucrose bound in each cap was stained with a water-soluble, food-grade dye to permit visual observation of the movement and relative concentration of sucrose dissolved in runoff water. In addition, spheres were painted gloss white to allow maximum visual interpretation of sucrose coverage and distribution. All runoff water from each sphere was collected and tested for sucrose content using a Brix scale assessed with an Atago hand refractometer (0-32%, +/-0.1%).

In our first experiment, we varied the concentration of paraffin in each cap to assess the impact of paraffin content on sugar output and cap durability. We formed two-inch fluted caps (50 grams each) containing 10%, 15%, 20%, or 25% paraffin, and subjected five replicates of each disc type to eight inches of artificially applied rainfall. In all trials of these caps, rain was applied at a rate of one inch per hour, and spheres received no more than one inch per day to simulate the periodic rains of summer field conditions. After each inch of rainfall, we calculated the total mass of sugar put out by each cap, the mass of sugar lost to rainfall (by collecting and analyzing runoff water from each sphere), and the amount of sugar left on the surface of each sphere. Initial data drawn from caps containing 15% and 20% paraffin were encouraging, leading us to test the acceptability of spheres to flies after two, four, six, and eight inches of rainfall. In this trial, 50 flies were exposed (individually) to each treatment. Flies were allowed to forage freely on spheres for a maximum of 600 seconds. Total residence time and time spent feeding were recorded for each fly.

In our second experiment, we varied the total mass and diameter of caps in an attempt to heighten both the concentration and duration of the sugar output of each cap. For this trial, we produced three types of caps: 1) 2-inch diameter, 50 grams, fluted; 2) 2-inch diameter, 75 grams, fluted; and 3) 2½-inch diameter, 75 grams, fluted. As in the previous experiment, we subjected five replicates of each cap type to eight inches of artificially applied rainfall in one-inch increments. After each rainfall interval, we assessed the total mass of sugar put out by each cap, the mass of sugar lost to runoff, and the amount of sugar left on the surface of each sphere. Given the limited success of either of the larger caps, we did not perform fly feeding tests on any spheres in this experiment.

In our third experiment, we attempted to enhance the performance of sugar-release caps by capitalizing on the observation that a small amount of water is absorbed by and moves through the paraffin/sucrose matrix of each cap. To enhance the availability of sucrose bound within the wax matrix, we reshaped our 2000 field-standard caps (15% paraffin, 2-inch diameter, 50 grams) such that eight shallow reservoirs were pressed into the top of each cap. As an alternative to fluted caps that channel rainfall off of wax/sugar caps, these caps were designed to retain a small amount of water (roughly five milliliters) in reservoirs atop each cap, allowing held water to percolate through the slightly porous cap body. This percolation effect has four advantages over previous cap styles: 1) the slowly developing sucrose-bearing runoff is highly concentrated to consistently stimulate fly feeding; 2) very little sucrose runs off onto fruit and foliage beneath traps, limiting fungal growth; 3) the entire mass of sucrose in each cap is eventually used, dramatically increasing the endurance of each wooden PTS; and 4) a very small amount of rainfall or dew (less than 0.1 inch) is needed to recharge the spheres with sucrose. In this experiment, we directly compared these modified caps with our 2000 field standard. As in previous trials, five spheres of each type were exposed to artificially generated rainfall in 1-inch increments. After each rainfall interval, we assessed the total mass of sugar put out by each cap, the mass of sugar lost to runoff, and the amount of sugar left on the surface of each sphere.

Our final experiment in this trial aimed at deterring rodents from feeding on field-deployed wax/sugar caps atop wooden PTS. Up to and during the 2000 field season, we tested chemical additives (cayenne pepper and bitter watermelon concentrate) for their ability to deter rodent feeding on caps. Field and laboratory data from these trials concluded that bitter watermelon extract (up to 5% concentration) had no rodent-deterrent effect, while cayenne pepper (up to 10% concentration) had only little deterrent effect. Further, the negative impact of these additives on cap structural integrity far outweighed the potential benefits of rodent deterrence. Therefore, we determined that a physical barrier must be integrated into the sphere/cap system to bar rodents from reaching and damaging the vulnerable wax/sugar caps. We constructed five types of wire guards (all formed of 1/8-inch grid hardware cloth) for wax/sugar caps atop wooden PTS: 1) bottom guard only, 2) top guard only, 3) side guard only, 4) reusable top/side guard combination, and 5) fixed top/

bottom/side guard combination. Five caps of each treatment along with five unprotected caps were placed atop spheres and offered to numerous and remarkably aggressive wild gray squirrels. Assessments of physical damage (as percentage of cap mass consumed) were made daily for two weeks after deployment.

Results

As hypothesized for our first experiment, wax/sugar discs formulated with lower rates of paraffin (10%-15%, Table 1) released a greater amount of sugar under rainfall than discs formulated with higher rates of paraffin (20%-25%). Although superior at the outset, discs formulated with the lowest rate of paraffin (10%) only released an acceptable amount of sucrose (>5.0 grams per inch of rain) through four inches of artificially applied rainfall. Conversely, caps formulated with the greatest amount of paraffin (25%) never provided an adequate release of sucrose. Caps formulated with 15% paraffin performed somewhat better, offering an acceptable release of sugar through five inches of accumulated rainfall, and caps formulated with 20% paraffin released slightly less sugar than those formulated with 15% paraffin through the first six inches of rainfall. However, sugar release from caps of 20% paraffin was by far the most consistent through simulated mid-season treatments (four to eight inches accumulated rainfall). Therefore, we elected to conduct bioassays comparing acceptability of spheres equipped with caps formulated with 15% and 20% paraffin.

In the first half of bioassays (two to four inches of rainfall), feeding response of flies placed on spheres equipped with wax/sugar caps was excellent and equal between treatments (Table 2). In fact, through four inches of rainfall, both treatments yielded mean feeding times far greater than needed to ensure adequate uptake of toxicant. Further, both treatments stimulated 86% of exposed flies to feed for more than 30 seconds, suggesting that both density and coverage of sucrose on sphere surfaces remained sufficient after four inches of rainfall. After six inches of rainfall, however, neither treatment fared well. Effectiveness of spheres fitted with 15% paraffin caps retained only one-eighth of their feeding stimulant power after six inches of rainfall, while spheres fitted with 20% paraffin caps retained only one-half. Along with reduced duration of feeding, far fewer flies were willing to feed on spheres at all, strongly indicating that after six inches of rainfall, neither treatment could be reliable as a control mechanism for AMF.

In our second experiment, we compared the sugar

Table 1. Mean release of sucrose from experimental wax/sugar caps. Data indicate mass of sucrose (grams) in runoff water after exposure to artificially generated rainfall. Sugar release greater than 5.00 grams per inch of rainfall is needed to reliably stimulate fly feeding. All tested caps were 50 grams total mass, 2-inch diameter, fluted design.

	Sphere cap formulation (% paraffin)			
Rainfall (inches)	10	15	20	25
1	6.54	4.95	3.68	2.45
2	5.00	5.97	5.02	2.27
3	6.20	5.27	4.01	2.30
4	5.46	6.17	5.77	2.04
5	4.55	5.22	4.60	2.36
6	3.18	3.76	3.57	1.42
7	2.02	2.43	3.37	1.06
8	0.91	1.70	3.05	0.61
Total (grams)	33.86	35.47	33.07	14.51
% Sugar Released	75.2	83.5	82.7	38.7

Table 2. Duration and propensity of apple maggot fly feeding on spheres equipped with wax/sugar caps after exposure to artificially generated rainfall. For each treatment, 50 flies were exposed (individually) and allowed to forage freely on spheres for a maximum of 600 seconds.

	Mean fly feeding time (sec.) Sphere cap formulation		Flies feeding >30 seconds (%) Sphere cap formulation	
Rainfall (inches)	15%	20%	15%	20%
2	366.7	439.1	84.0	88.0
4	403.3	340.7	86.0	86.0
6	54.0	163.1	24.0	52.0
8	46.1	68.4	16.0	28.0

Table 3. Comparison of release of sucrose by two styles of wax/sugar caps and comparison of retention of released sucrose on wooden spheres.

	Sugar (grams) in runoff water Sphere Cap Style		Sugar (mg/cm^2) retained on sphere Sphere Cap Style	
Rainfall (inches)	Fluted	Reservoir	Fluted	Reservoir
1	4.95	2.55	3.3	11.3
2	5.97	1.85	2.7	7.0
3	5.27	1.69	2.5	5.3
4	6.17	1.54	2.4	4.5
5	5.22	1.45	2.2	4.4
6	3.76	1.27	1.7	4.2
7	2.43	1.16	1.1	3.9
8	1.70	1.14	0.8	3.8
Total (grams)	35.47	12.65		
% Sugar Released	83.5	29.8		

release from caps of varying sizes. By increasing the cap height by 50%, our intent was to maintain steady sugar release over a longer period. Unfortunately, increasing cap height did not enhance either concentration or duration of sugar release. By increasing the cap diameter to 2 ½", we were able to substantially increase the amount of sugar put out by each cap. However, by extending the outer edge of the cap closer to the diameter of the sphere, we eliminated the potential for even coverage by sugar-bearing runoff. It was apparent under visual observation of the movement of stained sucrose that although we had drastically increased the amount of sugar put out by each cap, very little released sugar remained on the sphere surface. Therefore, we abandoned any further testing of fluted wax/sugar caps larger than 2-inch diameter.

Although the previous experiment did not yield an improvement over our 2000 field-model sugar-release caps, we found that all caps tested retained a substantial amount of sucrose within the cap bodies long after they had stopped releasing sugar to the sphere surfaces. Unfortunately, with a fluted cap style (reliant on release of sugar from the outside surfaces of the cap), the remainder of solid sucrose is too deeply embedded in the wax matrix to be readily available for dissolution in rainfall. However, by direct observation of the movement of rainfall onto and off of these caps, we determined that a small amount of water moves slowly through the wax matrix and is released to the sphere surface at the bottom of the cap. For our third experiment, we compared the rate of sugar release from fluted caps versus release from new caps partitioned at the top to allow retention of a small reservoir of water. In assessments of sucrose found in runoff, fluted caps were superior (Table 3), maintaining greater than five grams of sugar release per inch of rainfall through five accumulated inches, while reservoir-style caps never exceeded three grams of sucrose release. However, visual observations indicated that both coverage and concentration of sucrose on spheres after drying were far greater on spheres fitted with new reservoir-style caps. This observation was confirmed by subsequent measurements of residual sucrose on the sphere surface (Table 3).

In our final experiment, we assessed the effectiveness of five types of rodent guards, all formed of hardware cloth. After only a day of exposure to wild gray squirrels, any caps with any unprotected surface were severely damaged. After one week, all caps were consumed entirely, with the exception of those fitted with an embedded top/bottom/side guard combination. At the close of the two-week trial, all of these fully protected caps remained intact, although the integrity of the guard system showed signs of wear. We are confident, though, that caps constructed with a fully integrated wire guard can withstand the more lenient assaults of standard orchard-dwelling rodents.

Conclusion

Given the variables of wax type, cap formulation and size, shape, and density of cap, a vast array of sugar release systems remain to be tested for use on pesticide-treated wooden spheres. However, through trials to date, we have arrived at an improved sugar delivery system for testing under commercial orchard conditions. Although these caps are still under study, their performance has exceeded any other style tested to date, and they hold the potential to markedly enhance the effectiveness, practicality, and commercial viability of wooden PTS. We will carry forward with field trials of spheres equipped with the style of caps developed here: 2-inch diameter, 15-20% paraffin, 50 grams total mass, reservoir design, formed under 20 tons of pressure, and fitted with an integrated rodent guard.

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