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ORIGINAL PAPER

# Evaluation of aerosol devices for simultaneous disruption of sex pheromone communication in *Cydia pomonella* and *Grapholita molesta* (Lepidoptera: Tortricidae)

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**Abstract** A two-year study was conducted evaluating Puffer® aerosol dispensers (Suterra LLC, Bend, OR, USA) for mating disruption of codling moth, *Cydia pomonella* (L.), and the oriental fruit moth, *Grapholita molesta* (Busck). The Puffer® dispenser consists of a pressurized metal canister loaded with pheromone active ingredients dissolved in solvent and housed within a circuit-controlled, plastic dispensing cabinet programmed to release an aerosol spray of pheromone at regular intervals. Puffers® were deployed at the label-recommended rate of 2.5 $ha^{-1}$ and released ca. 5–10 mg of pheromone (depending on treatment) per 15 min during a 12-h cycle beginning each day at 15:00 h for the duration of the season. In 2005, commercially-managed apple plots (3.2–4.9 ha) were treated with Puffers® releasing both species' pheromone simultaneously (dual-species) or with twice the number of adjacently-deployed Puffers® (4–6 m apart) releasing each individual species' pheromones (single-species), while maintaining comparable overall release rates of pheromone between these two treatments. Plots 100 m away and not treated with pheromone served as the control. Disruption of male *C. pomonella* and *G. molesta* orientation to pheromone-baited traps was 46–75 and 91–98%, respectively, in Puffer®-treated plots compared with untreated controls. There was no statistical difference in moth disruption between plots treated with dual-species and single-species Puffers®. Fruit injury was not statistically different between Puffer®-treated plots and control plots not receiving pheromone. In 2006, disruption of male moth orientation to traps was 24–26 and 84–97% in Puffer®-treated plots (2.9–5.7 ha) for *C. pomonella* and *G. molesta*, respectively, compared with untreated controls. During this season, fruit injury was lower in pheromone-treated plots compared with untreated controls at mid-season, but not at pre-harvest. Combining the pheromone of both species into single Puffer® units did not decrease efficacy of disruption compared with deploying twice as many Puffers® releasing a similar amount of each individual species' pheromone suggesting that multi-species disruption using Puffers® is a viable option. However, we conclude that the efficacy of disruption attained with low-densities (2.5 $ha^{-1}$) of Puffers® at the moth densities recorded in this study is insufficient for effective control of *C. pomonella* without input of companion insecticides.

**Keywords** Applied chemical ecology · Codling moth · Oriental fruit moth · Mating disruption · Puffers® · Codlemone

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## Introduction

The codling moth, *Cydia pomonella* (L.), and the oriental fruit moth, *Grapholita molesta* (Busck), are worldwide pests of pome and stone fruits. *G. molesta* is a key pest of peaches, plums, nectarines, apricots, and apples, while *C. pomonella* primarily infests apples, pears, and walnuts in major growing regions throughout Europe, Asia, America, Africa, Australia, and New Zealand (Chapman and Lienk

1971; Vickers 1990; Vickers and Rothschild 1991; Rothschild and Vickers 1991). Resistance to organophosphorus insecticides following prolonged overuse has developed in both species (Chapman and Barrett 1997; Pree et al. 1998; Kanga et al 2003; Reuveny and Cohen 2004).

Mating disruption, achieved by broadcasting synthetic pheromones into the crop atmosphere to disrupt mate finding, has been practiced and refined for both species for over two decades (Cardé and Minks 1995). Considerable effort has been channeled into development of effective disruption for *C. pomonella* in USA; currently over 54,000 ha of pome fruits and walnuts are treated with pheromone for disruption of this species (Gut et al. 2004). Successful implementation of mating disruption for these two key pests has led to reductions in the number of broad-spectrum insecticide sprays required for acceptable control (Rice and Kirsch 1990; Gut and Bruner 1998; Walker and Welter 2001; Calkins and Faust 2003).

Polyethylene-tube reservoir dispensers (Isomate Shin-Etsu Chemical Co. Tokyo, Japan) have been perhaps the most widely used formulation for mating disruption of both *C. pomonella* and *G. molesta*, particularly in North America (Thomson et al. 1999). Polyethylene-tube dispensers formulated for control of these pest species contain 75–250 mg of pheromone per unit and are hand-applied at 500–1000 units/ha. Although they have proven highly effective against *G. molesta* (Rice and Kirsch 1990; Pree et al. 1994; Trimble et al. 2001; Atanassov et al. 2002; Trimble et al. 2004), results have been inconsistent with *C. pomonella* (Cardé and Minks 1995; Gut et al. 2004; Epstein et al. 2006; Stelinski et al. 2006). The cost of labor associated with hand application has been cited as an impediment to broader adoption of mating disruption in USA (Gut et al. 2004).

Several other types of disruption formulations are available as alternatives to hand-applied dispensers. Sprayable pheromones consist of microscopic capsules that are deployed via air-blast sprayers alleviating the labor-cost associated with hand-application of reservoir dispensers (Kovanci et al. 2005; Il'ichev et al. 2006). Sprayables have proven highly effective for *G. molesta* (Trimble et al. 2004; Kovanci et al. 2005; Il'ichev et al. 2006); but, less effective for *C. pomonella* (Epstein et al. 2003; Knight and Larsen 2004). Hercon Disrupt CM flakes (Hercon, Emigsville, PA, USA) and Scentry NoMate CM Fibers (Scentry, Billings, MT, USA) (Swenson and Weatherston 1989) are also machine-applied to crops via custom applicators. Published reports on efficacy of the most recent versions of these formulations against *C. pomonella* and *G. molesta* are lacking.

Low-density, high-release dispensing systems like Puffers® (Shorey et al. 1996; Knight 2004) or Microsprayers (Isaacs et al. 1999) are deployed by hand, but at very low densities (ca. 2–3) per ha of crop. These dispensers emit an aerosol spray of solvent-diluted pheromone at electronic circuit-controlled intervals of ca. 15 min throughout the diel cycle. Shorey and Gerber (1996a) demonstrated a high degree of disruption efficacy (95–98%) with Puffers® (2.3 $ha^{-1}$) when deployed in 16 ha walnut orchards with low population densities of *C. pomonella*. Successful disruption with Puffers® was also demonstrated for *Spodoptera exigua* (Hübner) (Shorey and Gerber 1996b; Shorey et al.1996), *Platynota stultana* (Walsingham) (Shorey et al. 1996), and *Amyelois transitella* (Walker) (Shorey and Gerber 1996c).

Recently, in Michigan and much of the Eastern and Midwestern United States, *G. molesta* has emerged as a major pest of apples, requiring concurrent control with *C. pomonella* (Kovanci et al. 2005; Myers et al. 2006). Application of separate mating disruption formulations for each species, particularly labor-intensive hand-applied dispensers, is a serious obstacle to greater adoption of mating disruption (Gut et al. 2004). Multi-species disruption formulations targeting multiple closely related or unrelated species are a potential solution to both the problem of secondary pest outbreaks and the high cost of applying species-specific formulations for more than one pest. The concept of multi-species disruption with common dispensers has been proven effective for species sharing major pheromonal components and for distantly-related species with distinct components. For example, three sympatrically-occurring leafoller species [*Choristoneura rosaceana* (Harris), *Archips rosanus* (L.), and *A. argyrospilus* (Walker)], sharing (*Z*)-11-tetradecenyl acetate, were successfully disrupted with reservoir dispensers loaded with a 93:7 blend of (*Z*)-11-tetradecenyl acetate and (*E*)-11-tetradecenyl acetate (Deland et al. 1994). Similarly, both *C. rosaceana* and *Pandemis limitata* (Robinson) were simultaneously disrupted by reservoir dispensers loaded with a 98:2 blend of (*Z*)-11-tetradecenyl acetate and (*E*)-11-tetradecenyl acetate (Evenden et al. 1999). More recently, Judd and Gardiner (2004) demonstrated that hand-applied reservoir dispensers (500 $ha^{-1}$) loaded mainly with (*E*,*E*)-8,10-dodecadien-1-ol and (*Z*)-11-tetradecenyl acetate were effective in simultaneously disrupting moth orientation to traps and mating for *C. pomonella* and four leafroller species.

Aerosol dispensers represent an economically attractive technology for mating disruption of *C. pomonella* and *G. molesta* because such dispensers are deployed at very low densities (2–3 units/ha) and because individual units can be manufactured to co-release the pheromone of both species. Moreover, pheromonal active ingredients housed within such dispensers are protected from photodegradation and oxidation. The purpose of this study was to evaluate the latest version of Puffer® aerosol dispensers for concurrent disruption of *C. pomonella* and *G. molesta* in Michigan apple orchards. The specific objectives were to determine whether: (1) application of Puffers® at 2.5 units/ha of apple disrupts male moth orientation to attractive point sources and/or reduces fruit injury compared with paired non-disrupted control plots, and (2) Puffers® releasing a blend of both species' pheromones disrupt sexual communication equivalently to Puffers® releasing each species' pheromone separately.

## Materials and methods

### Field Sites, treatments, and experimental design: 2005

The objective of this study was to evaluate the Puffer® aerosol dispenser manufactured by Suterra LLC (Bend, OR, USA) for mating disruption of *C. pomonella* and *G. molesta*. The Puffer® aerosol dispenser consists of a pressurized metal canister loaded with pheromone active ingredients dissolved in solvent and housed within a circuit-controlled, plastic dispensing cabinet (32 × 15 × 12 cm) programmed to release pheromone every 15 min. The Puffer® cabinet is powered by four "D" batteries and operated by remote control. The treatments compared were: (1) Puffers® simultaneously dispensing both *C. pomonella* and *G. molesta* pheromone (dual-species), (2) Puffers® individually dispensing *C. pomonella* or *G. molesta* pheromone and deployed in tandem in adjacent trees 4–6 m apart (single-species), and (3) a no pheromone control. The experimental design was a randomized complete block with four replicates. The experiment was conducted in two commercially-farmed orchards located in southwest Michigan, USA and two orchards north of Grand Rapids, MI, USA. Orchards ranged from 10.2–26.5 ha in size and were sub-divided into 3 blocks; treatments were randomly assigned to each block. Dual- and single-species Puffer®-treated plots were 60 m apart; control blocks were 100 m away from Puffer®-treated plots. Buffers between treatments consisted of trees not treated with pheromone. Plot size and tree characteristics for each replicate are given in Table 1. All treatment blocks received the same commercial management regime, as needed, to prevent unacceptable levels of fruit injury at harvest (de Lame and Gut 2006). The experiment was conducted from 28 April to 12 September.

Puffer® pheromone canisters contained 384.0 g of active and inert ingredients per unit and released 40 µl of solution through a solenoid-metered valve per puff. The *C. pomonella* single-species canister contained 69.3 g of (*E*,*E*)-8,10-dodecadien-1-ol (codlemone) and released 6.9 mg of codlemone/40 µl puff. The *G. molesta* single-species Puffer® canister contained 48.0 g of a 93:6:1 blend of (*Z*)-8-dodecen-1-yl-acetate:(*E*)-8-dodecen-1-yl-acetate:(*Z*)-8-dodecen-1-ol and released 5.0 mg of this blend/40 µl puff. The combined *C. pomonella*–*G. molesta* Puffer® canister contained 69.4 g of codlemone and 24.0 g of the *G. molesta* pheromone blend and released 7.2 mg codlemone and 2.5 mg of the *G. molesta* pheromone blend/40 µl puff.

Puffers® were deployed at the manufacturer-recommended density of 2.5 dual- or single-species units (one for each species in adjacent trees 4–6 m apart) per ha. According to label recommendations, Puffers® were distributed around the orchard perimeter and placed on the 2nd tree from the plot edge with the nozzle directed toward the orchard interior. Puffers® were hung centrally in the upper third of the tree canopy. Puffers® were programmed to dispense a 40 µl puff of pheromone solution every 15 min during a 12-h cycle beginning each day at 15:00 h.

### Field Sites, treatments, and experimental design: 2006

No statistically-significant differences in orientational disruption of either *C. pomonella* or *G. molesta* males were

**Table 1** Description of orchards used in 2005 field trial comparing dual- and single-species Puffer®-treated plots versus untreated control plots

| Replicate | Treatment | Cultivar(s) | Block size (ha) | Tree spacing (m) | Tree height (m) |
|---|---|---|---|---|---|
| 1 | Dual species | Red chief | 4.0 | 4.6 × 5.5 | 4.6 |
| 1 | Single species | Red chief | 4.0 | 4.6 × 5.5 | 4.6 |
| 1 | Control | Red chief | 4.0 | 3.7 × 6.1 | 4.6 |
| 2 | Dual species | Rome, Jonathon, Delicious | 4.9 | 6.1 × 6.1 | 5.5 |
| 2 | Single species | Rome, Jonathon, Delicious | 4.9 | 6.1 × 6.1 | 5.5 |
| 2 | Control | Jonathon,Golden Delicious | 4.9 | 6.1 × 6.1 | 5.5 |
| 3 | Dual species | Empire, Delicious | 3.2 | 3.7 × 4.9 | 5.5 |
| 3 | Single species | Empire, Delicious | 3.2 | 3.7 × 4.9 | 5.5 |
| 3 | Control | Northern spy, Delicious | 3.2 | 3.7 × 4.9 | 5.5 |
| 4 | Dual species | Ida red, Delicious, Empire | 3.2 | 3.7 × 4.9 | 4.9 |
| 4 | Single species | Ida red, Delicious, Empire | 3.2 | 3.7 × 4.9 | 4.9 |
| 4 | Control | Rome, Empire | 3.2 | 3.7 × 4.9 | 4.9 |

recorded between the dual-species and single-species Puffer® treatments in 2005 (see "Results"). Therefore, in 2006, we only re-evaluated the dual-species Puffer® treatment versus untreated control plots. The two treatments compared were: (1) Puffers® simultaneously dispensing both *C. pomonella* and *G. molesta* pheromone and (2) a no pheromone control. The experimental design was a randomized complete block with three replicates. Treatment blocks were separated by 60–100 m. Plot size and tree characteristics for each replicate are given in Table 2. As before, each block was treated identically with commercial management sprays, as needed, to prevent unacceptable damage levels. The experiment was conducted from 25 April to 6 September.

Puffer® placement protocol was identical to that evaluated in the previous year. As before, units were programmed to dispense 40 µl of pheromone solution per 15 min interval during a 12-h cycle beginning each day at 15:00 h. Pheromone loading in dual-species Puffer® canisters was identical to that evaluated in 2005. Each pheromone canister contained 384.0 g of total active and inert ingredients and released 7.2 mg codlemone and 2.5 mg of the *G. molesta* pheromone blend (given above) per 40 µl puff.

Disruption of moth orientation

During each season, disruption of male moth catch in pheromone-baited delta traps (LPD Scenturian Guardpost, Suterra) was assessed. For *G. molesta*, traps were baited with red septum (The West Company, Linville, PA, USA) lures loaded with 0.1 mg of (*Z*)-8-dodecenyl acetate:(*E*)-8-dodecenyl acetate:(*Z*)-8-dodecen-1-ol in a 100:6:10 blend. For *C. pomonella*, traps were baited with grey holo-butyl septa loaded with codlemone (L2 CM lures, Trécé Inc., Salinas, CA, USA). Traps were hung ca. 2–3 m above ground level in the upper third of the tree canopy. New pheromone lures were deployed at the onset of each moth generation for a total of 2 and 3 replacements for *C. pomonella* and *G. molesta*, respectively, per season. In 2005, eight *C. pomonella* and four *G. molesta* pheromone-baited traps were placed within each replicate plot. In 2006, six *C. pomonella* and three *G. molesta* traps were placed within in each replicate block. Traps were distributed evenly throughout blocks at least 15.2 m away from plot borders. *C. pomonella* and *G. molesta* traps were separated by at least 9.1 m. Moths captured in traps were counted and removed weekly.

Fruit injury evaluation

During both seasons, fruit injury was evaluated in all replicate blocks following the first generation of *C. pomonella* and *G. molesta* moth flight and immediately prior to harvest. Thirty apples per tree, 15 high in the canopy and 15 low in the canopy, were examined from 20 trees per plot (600 fruit/plot total). In 2005, damaged fruit were cut open for identification of larvae. Larvae were examined under a microscope for *G. molesta* identification by determining presence of the anal comb; otherwise they were classified as *C. pomonella* (Stelinski et al. 2005a).

Statistical analyses

For the orientational disruption studies, moth catch data were transformed to ln $(x + 1)$ (which normalized the distributions and homogenized variance) and then subjected to analysis of variance (ANOVA). Fruit injury data were arcsine transformed prior to ANOVA. Differences in pairs of means were separated using Tukey's multiple comparisons test (SAS Institute 2000). Percent orientational disruption was calculated as 1 − (mean moth catch per trap in the pheromone-treated plot/mean moth catch per trap in the control plot) × 100.

## Results

Disruption of moth orientation: 2005

In each trial, moth catch was evenly distributed among the multiple monitoring traps per replicate block and therefore

**Table 2** Description of orchards used in 2006 field trial comparing dual-species Puffer®-treated plots with untreated control plots

| Replicate | Treatment | Cultivar(s) | Block size (ha) | Tree spacing (m) | Tree height (m) |
|---|---|---|---|---|---|
| 1 | Dual species | Golden delicious, Winesap | 3.6 | 6.1 × 7.3 | 5.5 |
| 1 | Control | Rome, Jonathan | 4.0 | 7.3 × 7.3 | 5.5 |
| 2 | Dual species | Rome, Ida red, Delicious, Golden delicious | 5.7 | 5.5 × 6.1 | 4.6 |
| 2 | Control | Rome, Ida red, Delicious, Golden delicious | 1.6 | 6.1 × 6.1 | 4.6 |
| 3 | Dual species | Delicious, Jonathan | 2.9 | 4.9 × 6.7 | 3.7 |
| 3 | Control | Smoothee gold | 1.6 | 3.7 × 5.5 | 3.7 |

averaged for statistical comparisons among treatments. During the first generation flight, significantly ($F = 16.2$; $df = 6{,}11$; $P < 0.001$) fewer male *C. pomonella* were captured in plots treated with dual-species and single-species Puffers® compared with controls (Table 3). Also, male *C. pomonella* catch was not statistically ($P > 0.05$) different between dual- and single-species Puffer® treatments (Table 3). For the second generation flight, male *C. pomonella* captures were significantly ($F = 10.1$; $df = 6, 11$; $P = 0.01$) reduced in both dual- and single-species Puffer®-treated plots compared with control plots (Table 3). Once again, there was no significant difference ($P > 0.05$) in male catch between the two Puffer® treatments (Table 3). Disruption of male *C. pomonella* orientation to traps in dual-species Puffer® plots was 75 and 73% for the first and second-generations, respectively. In plots treated with single-species Puffers®, percent orientational disruption of male *C. pomonella* to traps was numerically lower; only 46 and 65% inhibition of moth catch was recorded during the first and second flights, respectively.

Captures of male *G. molesta* were significantly reduced in dual- and single-species Puffer®-treated plots in both the first ($F = 5.1$; $df = 6, 11$; $P = 0.05$) and combined second and third ($F = 5.4$; $df = 6, 11$; $P = 0.03$) generations of moth flight, respectively (Table 3). During the first and combined second and third generations, there was no significant ($P > 0.05$) difference in the mean number of male *G. molesta* captured between plots treated with dual- and single-species Puffers® (Table 3). Disruption of male *G. molesta* orientation to traps was 91–98% in both dual- and single-species Puffer®-treated plots compared with controls during both first and combined second and third generations.

## Fruit injury: 2005

Following the first generation of moth flight for both species, there was no significant difference ($F = 0.2$; $df = 6, 11$; $P = 0.5$) in mean fruit injury between plots treated with dual-species Puffers® (0.1 ± 0.1%), combined single-species Puffers® (0.1 ± 0.1%), and control plots (0.1 ± 0.1%). All of the collected larvae infesting fruit were identified as *C. pomonella*. At pre-harvest, there also was no significant ($F = 2.3$; $df = 6, 11$; $P = 0.2$) difference in fruit injury between the three treatments; injury for dual-, single-species, and control plots averaged 0.4 ± 0.1, 0.1 ± 0.1, and 0.5 ± 0.2%, respectively.

## Disruption of moth orientation: 2006

Mean captures of male *C. pomonella* in dual-species Puffer®-treated plots were not significantly ($F = 0.6, 2.1$; $df = 2, 5$; $P = 0.4, 0.1$) different from those in control plots during both the first and second generations of moth flight, respectively (Table 4). Percent orientational disruption was only 24 and 26% during the first and second generations, respectively.

Significantly ($F = 12.5, 11.1$; $df = 2, 5$; $P = 0.05$) fewer male *G. molesta* were captured in dual-species Puffer®-treated plots compared with controls in both the first and combined second and third generations of moth flight; respectively (Table 4). Disruption of male orientation to traps in dual-species Puffer®-treated plots was 84 and 97% during the first and combined second and third generations, respectively.

## Fruit injury: 2006

Following the first generation of moth flight, there was no fruit injury detected in plots treated with the dual-species Puffers®; an average of 0.3 ± 0.3% injury was detected in companion control plots. At pre-harvest, there was no significant ($F = 0.4$; $df = 2, 5$; $P = 0.3$) difference between fruit injury recorded in dual-species Puffer®-treated plots (0.3 ± 0.3) and control plots (0.2 ± 0.1).

# Discussion

The efficacy of Puffer® aerosol dispensers (Suterra LLC) in disrupting male moth orientation to baited traps was superior for *G. molesta* compared with *C. pomonella*. Although

**Table 3** Mean number of male moths captured in pheromone traps in plots treated with dual- or single-species Puffer® treatments versus untreated control plots (2005)

| | Mean (SE) captures of male moths per trap per sampling period | | | | | |
|---|---|---|---|---|---|---|
| | First generation | | | Second and third generations[a] | | |
| Treatment | Dual-species | Single-species | Control | Dual-species | Single-species | Control |
| *C. pomonella* | 1.6 a (0.7) | 3.5 a (1.5) | 6.5 b (2.0) | 5.0 a (2.3) | 6.4 a (3.6) | 18.5 b (8.6) |
| *G. molesta* | 0.5 a (0.4) | 1.6 a (1.5) | 26.4 b (17.8) | 4.4 a (3.1) | 1.8 a (0.7) | 70.1 b (50.2) |

Means within a row and generation followed by the same letter are not significantly different (ANOVA, $P > 0.05$) followed by Tukey's mean separation ($P > 0.05$)

[a] Second generation for *C. pomonella*; combination of second and third generation flights for *G. molesta*

**Table 4** Mean number of male moths captured in pheromone traps in plots treated with dual-species Puffer® treatments versus untreated control plots (2006)

| | Mean (SE) captures of male moths per trap per sampling period | | | |
|---|---|---|---|---|
| | First generation | | Second and third generations[a] | |
| Treatment | Dual-species | Control | Dual-species | Control |
| *C. pomonella* | 8.2 (4.0) a | 6.6 (2.6) a | 9.8 (4.2) a | 13.3 (2.3) a |
| *G. molesta* | 9.2 (9.1) a | 58.0 (45.6) b | 1.3 (0.9) a | 44.6 (33.9) b |

Means within a row and generation followed by the same letter are not significantly different (ANOVA, $P > 0.05$) followed by Tukey's mean separation ($P > 0.05$)

[a] Second generation for *C. pomonella*; combination of second and third generation flights for *G. molesta*

84–98% disruption was recorded for *G. molesta* during the two consecutive seasons, only 26–75% disruption was achieved for *C. pomonella*. This level of disruption is considered poor and may be below that needed to achieve adequate fruit protection for *C. pomonella* without the input of companion insecticides. Our results with *C. pomonella* are in contrast to those reported by Shorey and Gerber (1996a) who tested an earlier version of Puffers®. Their study demonstrated 95–98% disruption of *C. pomonella* in walnuts at a Puffer® deployment rate per ha similar to ours; each unit releasing ca. 240 mg of codlemone/day. However, their study was conducted under comparatively lower population densities of *C. pomonella*. Furthermore, their experiments were conducted in walnut orchards with trees of greater height and canopy size than the 3.7–5.5 m apple trees investigated in the current study. Greater canopy size may reduce wind speed and prevent pheromone loss resulting in better disruption (Suckling et al. 2007). Perhaps the combination of larger canopy size of walnut than apple orchards and lower population densities of *C. pomonella* explains the difference in efficacy between the Shorey and Gerber (1996a) study and the current results. However, it is also possible that deployment of *G. molesta* pheromone impacted disruption of *C. pomonella*; this hypothesis deserves further investigation.

The efficacy of disruption in plots treated with Puffer® dispensers co-releasing the pheromones of both *C. pomonella* and *G. molesta* was equivalent to that recorded with twice as many Puffer® units individually releasing species-specific pheromones at comparable overall release rates of pheromone per treatment. Thus, co-releasing the pheromones of both species from a common unit does not compromise efficacy, showing promise for simultaneous multi-species control without the need for deploying species-specific formulations. The current results are consistent with a recent study by Il'ichev et al. (2007) comparing Isomate C/OFM TT, which simultaneously release the pheromone components of both *C. pomonella* and *G. molesta* with a combined treatment of both Isomate CTT and OFM Rosso, releasing each species' pheromone individually. Disruption of both species was equivalent between plots treated with the dual-species reservoir dispensers and the combination of the two single-species dispensers (Il'ichev et al. 2007).

The high release rate of pheromone from aerosol dispensers, such as Puffers®, is thought to compensate for their low application densities. Solvent-diluted pheromone sprayed from these dispensers adheres onto foliage and droplets of pure pheromone accumulate over time on the source tree. This may result in large and highly concentrated plumes wafting great distances downwind of the source trees to disrupt moth communication over large areas (Knight 2004). Reducing the cost of labor for treatment application while maintaining overall efficacy comparable to that achieved with many hundreds of reservoir devices applied by hand is the desired goal. However, there is mounting corroborating evidence that disruption of various moth species is superior via higher rather than lower densities of pheromone release sites at common overall release rates of pheromone per ha (Charlton and Cardé 1981; Palaniswamy et al. 1982; Suckling et al.1994; de Lame 2003; Stelinski et al. 2005a; Miller et al. 2006a,b). This has also been recently confirmed by Epstein et al. (2006) for *C. pomonella*. In that recent study, the density of pheromone point sources per ha of crop was varied from 1 to 1,000 while maintaining the total number of Isomate C Plus dispensers at 1,000 $ha^{-1}$. Disruption of pheromone-baited traps increased as a function of increasing dispenser density. Correspondingly, fruit injury decreased as the density of Isomate dispensers was increased and was lowest in plots treated with 1,000 evenly-distributed dispensers/ha. These results are consistent with a recent study by Suckling et al. (2007) with the light-brown apple moth, *Epiphyas postvittana* (Walker), where disruption with Puffers® did not exceed 90% and was below that achieved with 1,000 polyethylene tube dispensers/ha. Thus, under moderate to high *C. pomonella* population densities, it may not be possible to achieve effective control with mating disruption by decreasing pheromone dispenser point source density with a compensating increase in release rate per dispenser.

A recent investigation has shown that seconds-long exposure of male *C. pomonella* to Isomate C Plus dispensers nearly eliminates subsequent male moth responses to otherwise highly-attractive codlemone lures in the flight tunnel (Stelinski et al. 2006). This suggests that habituation following brief pheromone exposure may be an important mechanism contributing to mating disruption of *C. pomonella*. Shorey and Gerber (1996a) estimated that their Puffer® treatment achieved an airborne concentration of pheromone of approximately 6.3 ng/m$^3$ of air, which may induce habituation. However, this is below the concentration required to adapt the antennae of male *C. pomonella* (Judd et al. 2005; Stelinski et al. 2005b), suggesting that other mechanisms may be contributing to disruption with Puffers®. Determining the mechanism(s) by which Puffers® disrupt sexual communication in moths needs to be further investigated. Questions that require answering include: (1) What is the active space of Puffer® plumes? (2) Are male moths attracted to the large plumes generated by these devices and the buildup of pheromone adhering to nearby tree surfaces? If so, following anemotactic orientations of males along these presumably large-distance plumes; (3) How is their subsequent behavior affected? or, (4) Do Puffers® disrupt males by a non-competitive mechanism such as camouflage or sensory imbalance? Answers to these and related questions may lead to improvement of Puffer® efficacy.

Additional research and development of low density, aerosol dispensers such as Puffers® is warranted. This technique is highly attractive to both the commercial industry and growers given the potential cost savings due to reduced labor compared with applying many hundreds of species-specific reservoir dispensers per ha. Shorey and Gerber's (1996a) report of high efficacy with Puffers® (2.3 ha$^{-1}$) suggests promise against *C. pomonella* at low population densities. Knight (2004) also reported effective disruption of *C. pomonella* by deploying Puffers® at 1 unit/ha in combination with a 10–20 m wide band of Isomate C Plus dispensers surrounding the Puffer®-treated plots and deployed at 1,000 dispensers per ha. In that study, *C. pomonella* population densities were also very low with cumulative moth catches in pheromone traps below 10 males per season.

One potential avenue to explore is a dispenser that releases pheromone and is deployed at rates that are intermediate between lower-density Puffers® (2–3 ha$^{-1}$) and higher-density Isomate C Plus reservoir dispensers (1,000 ha$^{-1}$). Such a dispenser technology could potentially exploit competitive attraction better than Puffers® deployed at 2–3 ha$^{-1}$, if plume-following is an important component of disruption by these devices. Concurrently, such devices may exploit habituation to a greater degree than Isomate C Plus dispensers (Stelinski et al. 2006) given their potential higher release rate of pheromone per dispenser. Furthermore, such dispensers of intermediate release rate and application density might still reduce the total application cost relative to formulations requiring application of a 1,000 units/ha, while maintaining commercially-required efficacy.

In 2005, there was no reduction in fruit damage in either the single-species or dual-species Puffer® treatments relative to plots not treated with pheromone. All of the injury was attributed to *C. pomonella* for which disruption was poor. In 2006, mid-season fruit injury following the first generation of moth flight was reduced compared with the no pheromone control; but, this was not the case at preharvest. Furthermore, disruption of moth catch in traps was moderate to poor, particularly for *C. pomonella*. The level of orientational disruption recorded over this 2-year study was insufficient to recommend use of Puffers® for control of either species as a stand-alone tactic in Michigan apple orchards. Our data suggest that use of Puffers® for *G. molesta* management may be feasible; however, the low degree of efficacy recorded for *C. pomonella* does not justify recommendation of this technology for management of this species in Michigan apples.

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