Studies on Oriental Fruit Moth (Lepidoptera: Tortricidae)  
Pheromone Microcapsules Using Various Tree Fruit  
Species, Cultivars, and Application Methods

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ABSTRACT  
The number of microcapsules containing pheromone of the  
oriental fruit moth, Grapholita molesta (Busck), was determined on leaves  
den from apple, Asian and European pear, peach, sweet and tart cherry, and plum  
trees. In addition, we compared the number of microcapsules on apple and  
peach leaves using a laboratory leaf dip application and a field airblast sprayer  
application. Finally, we compared the number of microcapsules on two apple  
and peach cultivars after airblast sprayer applications of microencapsulated  
pheromone. The bottom surface of ‘Gala’ apple leaves had microcapsule density  
of 0.47, the highest among the different tree fruits. The bottoms of ‘Shinko’  
Asian pear had the lowest microcapsule density of 0.09 followed by the tops  
of ‘Bluebell’ plum and ‘Columbia’ sweet cherry leaves both with density of 0.10.  
The greater than 3-fold difference between the fruit leaves with the highest  
and lowest numbers of microcapsules may indicate the need for rate specific  
recommendations on different species of fruit trees. The number of microcap-  
sules on apple and peach leaves treated with laboratory leaf dips was 8- to  
60-fold greater than the number of microcapsules on field-treated leaves. Al-  
though laboratory treatments eliminated other potentially confounding field  
variables, they did not accurately represent microcapsule numbers on leaves  
treated with an airblast sprayer. There were significant differences in micro-  
capsule abundance on ‘Delicious’ and ‘Gala’ apple leaves and ‘Encore’ and ‘Red  
Haven’ peach leaves. Trichome abundance and cuticle structure may be re-  
sponsible for the differences in the number of microcapsules on various tree  
fruit species and cultivars.

KEY WORDS  
pheromone, microencapsulation, Grapholita molesta, apple,  
pear, peach, cherry, plum

Microencapsulated pheromones have been studied for management of pests of  
cotton (Campion et al. 1981, Critchley et al. 1983, Moawad et al. 1991), corn  
(Albajes et al. 2002), stored products (Prevett et al. 1989), and timber (Beroza et  
al. 1974). Most of this research has been conducted against fruit pests. Research  
on the field efficacy of microencapsulated pheromone has been conducted on pests

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Microcapsules containing *G. molesta* pheromone differ in their abundance on mature and immature apple leaves, one year old wood, and fruit (Waldstein & Gut 2003). In addition, leaf surface can be an important variable influencing the number of oriental fruit moth pheromone microcapsules (Waldstein & Gut 2003, Waldstein & Gut 2004). Little is known about the differences in microcapsule abundance on different types of fruit leaves. Because oriental fruit moth is a pest on a variety of fruit crops including apples, pears, peaches, nectarines, apricots, cherries, and plums (Howitt 1993), there is the potential for *G. molesta* microencapsulated pheromone to be used on these different fruit crops. Therefore, we compared the number of oriental fruit moth pheromone microcapsules on the top and bottom surfaces of apple, pear (Asian and European), peach, cherry (sweet and tart), and plum leaves.

Studies have been conducted on the number of oriental fruit moth pheromone microcapsules on apple leaves using laboratory leaf dip applications (Waldstein & Gut 2003, Waldstein & Gut 2004). In the field, the numbers of microcapsules on leaves may be substantially less than observed under laboratory conditions using the same concentration with a leaf dip application. Bioassay studies have demonstrated that higher concentrations of pesticides are necessary for sprayer applications under field conditions to achieve the same mortality as leaf dip treatments (Agnello et al. 1994, Horowitz et al. 1997, Stansly et al. 1998). Factors that influence spray coverage in the field (e.g., weather, sprayer type, tree size, planting density, and density of the leaf canopy; Johnstone 1985, Black & Bukovac 1996, Bohmont 1997) may be responsible for lower concentrations on foliage sprayed in the field than leaf dip treatments. The value of using a leaf dip application under laboratory conditions is that it eliminates these variables and allows for a relative comparison of microcapsule abundance. The value of using an airblast sprayer application is that it gives a more realistic depiction of microcapsule abundance in commercial orchards. Therefore, we compared these two application methods to gain a better understanding of the number of microcapsules on apple and peach leaves under laboratory and field conditions. In addition, the number of pheromone microcapsules on leaves from ‘Gala’ and ‘Delicious’ apple cultivars were compared after applications with an airblast sprayer to determine if cultivar differences existed.

**Materials and Methods**

**Tree fruit comparison with laboratory leaf dips.** Twenty-five mature leaves were collected from one to three fruit trees at the Missouri State Fruit
Experiment Station, Mountain Grove, Missouri on 16 June, 23 June, 30 June, and 9 July 2003. A total of 100 leaves from the four replicates were collected from the following cultivars: ‘Gala’ apple, ‘Shinko’ Asian pear, ‘Duchess de Angloeme Bronze’ European pear, ‘Loring’ peach, ‘Columbia’ sweet cherry, ‘Montmorency’ tart cherry, and ‘Bluebell’ plum trees. While we were still in the field, we placed the leaves in plastic bags and stored them in a lunchbox cooler to reduce moisture loss. The leaves then were brought into the laboratory and dipped for 5 sec in beakers containing 200 mL of water and 45.8 \mu L of Checkmate® OFM-F microencapsulated pheromone for oriental fruit moth (22.06% Z-8 dodecenyl Acetate, 1.40% E-8 Dodecenyl Acetate, and 0.2% Z-8 Dodecenol, Suterra LLC, Bend, Oregon). The concentration of the solutions in beakers was equivalent to 86.6 mL of Checkmate® OFM-F in 378.5 L of water (2.93 fl oz Checkmate® OFM-F in 100 gal of water). After treatment with microencapsulated pheromone, the leaves were placed on waxed paper to air dry, and microcapsules were counted.

**Laboratory versus field application.** Leaves were collected from ‘Gala’ apple and ‘Encore’ and ‘Red Haven’ peach trees for the leaf dip application 1–3 d before airblast sprayer applications of microencapsulated pheromone. Leaves were brought into the laboratory and dipped for 5 sec in beakers containing 200 mL of water and 45.8 \mu L of Checkmate® OFM-F (2.93 fl oz Checkmate® OFM-F in 100 gal of water) according to the method previously described for the different tree fruit leaves. Leaves were also removed 2–6 h after microencapsulated pheromone was applied with an airblast sprayer (FMC DP100, FMC Corporation, Jonesboro, Arkansas) at the labeled rate of 214.5 mL/ha (2.93 fl oz/acre; 49.5 g active ingredient/ha) in a spray volume of 153 L/ha (100 gal/acre). Microencapsulated pheromone was applied a total of six times using the airblast sprayer at 6- to 9-d intervals. Fifteen leaves per apple and peach tree on a total of three to four randomly selected trees were removed for both leaf dip and airblast sprayer applications. Leaves were selected from the third to the sixth leaf from the distal end of the terminal to decrease potential variability in leaf age. Leaves were collected in an even distribution around each tree at a height of one to two meters on the outer portion of the leaf canopy. A total of six replicates of leaves were sampled from apple and peach trees for both application types.

**Cultivar comparison with field application.** Apple. Checkmate OFM-F microencapsulated pheromone was applied a total of four times at 7–9-d intervals to an apple block with ‘Gala’ and ‘Delicious’ trees. The total size of the apple block was 1.05 ha (2.6 acres), and the ‘Gala’ and ‘Delicious’ trees comprised 0.40 ha (1.0 acres) of the total. Four of the sixteen trees in each row were ‘Gala’ and four of sixteen were ‘Delicious’ trees. The apple trees were 13-yr old with 4.6 m (15 ft) between trees and 6.1 m (20 ft) between rows.

Peach. Checkmate OFM-F microencapsulated pheromone was applied in a 0.89-ha (2.2 acres) block containing four rows of ‘Encore’ and four rows of ‘Red Haven’ peach trees. The peach trees were 14-yr old with 6.1 m (20 ft) between trees and 6.1 m (20 ft) between rows. A total of seven applications were made on one-half row of ‘Encore’ trees and eight applications were made on one-half row of ‘Red Haven’ trees. Microencapsulated pheromone was applied 6–15 d apart on the two peach cultivars. ‘Encore’ and ‘Red Haven’ were not sprayed and sampled on the same day because they were in separate rows and insufficient space was available to spray them separately and perform the objectives of a simultaneous study using microencapsulated pheromone in the same block. Fifteen leaves per
apple and peach tree on a total of three to four randomly selected trees were sampled 2–6 h after each microencapsulated pheromone application.

**Microcapsule counts.** A fluorescent dye (0.10%) was microencapsulated with the oriental fruit moth pheromone by Suterra chemists so that microcapsules could be counted using an UV light (Knight et al. 2004). Leaves were illuminated with an UV light (Spectroline Model BiB-150-P, 365 nm) to count the green fluorescing microcapsules. The entire leaf including both top and bottom surfaces were examined for microcapsules. Fluorescing microcapsules were counted with the naked eye protected by an UV visor. Because leaf surface area is a variable, a leaf area meter (LI-COR Model LI-3000) was used so that counts could be standardized to a per square centimeter surface area (microcapsule density).

**Statistical analysis.** The microcapsule density was normalized prior to analysis of variance (ANOVA) using a log (x + 1) transformation. Analysis was done using SAS program version 9.1 (SAS, 2004) to compare mean microcapsule density among fruit trees, laboratory and field treatments, field applications on ‘Gala’ and ‘Delicious’ apple trees, and field applications on ‘Encore’ and ‘Red Haven’ peach trees. Where significant differences occurred, means were separated using Fisher’s least significant difference (LSD) test.

**Results**

**Tree fruit comparison with laboratory leaf dips.** The bottom surfaces of apple (‘Gala’) leaves had a microcapsule density of 0.47, the highest density among the fruit leaf surfaces (Table 1). The bottoms of Asian pear (‘Shinko’) and peach leaves and the tops of plum (‘Bluebell’) and sweet cherry (‘Columbia’) leaves had the lowest number of microcapsules with densities of 0.09, 0.14, 0.10, and 0.10, respectively. There were significantly more microcapsules on the top than the bottom leaf surfaces of ‘Shinko’ Asian pear leaves. There were significantly more microcapsules on the bottom than the top leaf surfaces on ‘Gala’, ‘Columbia’, ‘Montmorency’, and ‘Bluebell’ apple, sweet cherry, tart cherry, and plum leaves, respectively. The number of microcapsules on the tops and bottoms of ‘Duchess de Angloeme Bronze’ European pear and ‘Loring’ peach leaves was not significantly different. The largest difference in leaf surfaces occurred with plum leaves. The number of microcapsules on the bottoms of plum leaves was 2.3-fold greater than the top leaf surfaces.

**Laboratory versus field application.** Apple and peach leaves treated with microencapsulated pheromone by laboratory leaf dips had significantly higher densities than by field applications using an airblast sprayer (Table 2). The greatest differences between the application types occurred on ‘Gala’ apple leaves where the average number of microcapsules on leaves exposed by laboratory treatments was 60-fold greater than the field-treated leaves. On peach leaves, the average number of microcapsules on laboratory treated leaves was 8-fold and 30-fold greater than field treated leaves for the ‘Encore’ and ‘Red Haven’ cultivars, respectively.

**Cultivar comparison with field application.** After treatment with an airblast sprayer, the bottom surfaces of ‘Gala’ apple leaves had a significantly greater microcapsule density than the ‘Delicious’ apple leaves (Table 3). On the tops of the ‘Gala’ and ‘Delicious’ apple leaves, however, there were no significant
differences in microcapsule density. There were significantly higher numbers of microcapsules on the bottom of ‘Gala’ and ‘Delicious’ apple leaves than the top surfaces of the same leaves. The ‘Encore’ peach leaves had a significantly greater number of microcapsules on top and bottom leaf surfaces than the top and bottom surfaces of ‘Red Haven’ peach leaves. The number of microcapsules on the top and bottom surfaces of ‘Encore’ leaves was not significantly different. However, the number of microcapsules on the top of ‘Red Haven’ leaves was significantly greater than on the bottom of the same leaves.

**Discussion**

Similar to the results of a previous study (Waldstein & Gut 2003), leaf surface was an important variable affecting the microcapsule density. In addition to leaf surface, the species and cultivar of the fruit tree were additional variables that influenced the density of microcapsules on leaves. Differences in trichome abundance and cuticle structure have been proposed as factors responsible for differences in the number of pheromone microcapsules on tops and bottoms of leaves and immature and mature leaves (Waldstein & Gut 2003). Trichome abundance and cuticle structure may also have contributed to differences in the number of microcapsules among the different fruit leaves and cultivars. The greater than 3-fold difference between the fruit leaves with the highest and lowest numbers of microcapsules (i.e., ‘Gala’ and ‘Shinko’) may indicate the need for rate specific recommendations on different species of fruit trees. Further studies could be

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**Table 1. Mean (±SE) microcapsule density on top and bottom surfaces of tree fruit leaves dipped in breakers containing 45.8 μL Check-Mate® OFM-F microencapsulated pheromone in 200 mL of water (2.93 fl. oz./100 gal.)**

<table>
<thead>
<tr>
<th>Tree</th>
<th>Cultivar</th>
<th>Leaf surface</th>
<th>Mean a</th>
<th>SE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Apple</td>
<td>Gala</td>
<td>Top</td>
<td>0.28 b</td>
<td>0.006</td>
</tr>
<tr>
<td>Apple</td>
<td>Gala</td>
<td>Bottom</td>
<td>0.49 a</td>
<td>0.008</td>
</tr>
<tr>
<td>Asian Pear</td>
<td>Shinko</td>
<td>Top</td>
<td>0.16 ef</td>
<td>0.004</td>
</tr>
<tr>
<td>Asian Pear</td>
<td>Shinko</td>
<td>Bottom</td>
<td>0.09 h</td>
<td>0.003</td>
</tr>
<tr>
<td>European Pear</td>
<td>Duchess b</td>
<td>Top</td>
<td>0.21 cd</td>
<td>0.006</td>
</tr>
<tr>
<td>European Pear</td>
<td>Duchess b</td>
<td>Bottom</td>
<td>0.18 de</td>
<td>0.006</td>
</tr>
<tr>
<td>Peach</td>
<td>Loring</td>
<td>Top</td>
<td>0.15 ef</td>
<td>0.004</td>
</tr>
<tr>
<td>Peach</td>
<td>Loring</td>
<td>Bottom</td>
<td>0.14 fg</td>
<td>0.005</td>
</tr>
<tr>
<td>Sweet Cherry</td>
<td>Columbia</td>
<td>Top</td>
<td>0.10 gh</td>
<td>0.003</td>
</tr>
<tr>
<td>Sweet Cherry</td>
<td>Columbia</td>
<td>Bottom</td>
<td>0.17 def</td>
<td>0.003</td>
</tr>
<tr>
<td>Tart Cherry</td>
<td>Montmorency</td>
<td>Top</td>
<td>0.17 def</td>
<td>0.004</td>
</tr>
<tr>
<td>Tart Cherry</td>
<td>Montmorency</td>
<td>Bottom</td>
<td>0.27 b</td>
<td>0.006</td>
</tr>
<tr>
<td>Plum</td>
<td>Bluebell</td>
<td>Top</td>
<td>0.10 gh</td>
<td>0.003</td>
</tr>
<tr>
<td>Plum</td>
<td>Bluebell</td>
<td>Bottom</td>
<td>0.23 bc</td>
<td>0.005</td>
</tr>
</tbody>
</table>

*F = 7.6; df = 6, 21; P < 0.001.*

*aMeans followed by the same letter are not significantly different (Fisher’s protected LSD, P < 0.05).*

*bDuchess de Angloeme Bronze.*
Table 2. Mean (±SE) microcapsule density on apple and peach leaves treated with CheckMate® OFM-F microencapsulated pheromone by leaf dips in breakers under laboratory conditions or in the field on tree with an airblast sprayer at a rate of 86.6 mL of Checkmate® OFM-F in 378.5 L of water (2.93 fl. oz./100 gal.), Mountain Grove, Missouri, 2003.

<table>
<thead>
<tr>
<th>Tree</th>
<th>Cultivar</th>
<th>Treatment</th>
<th>Leaf surface</th>
<th>Mean&lt;sup&gt;a&lt;/sup&gt;</th>
<th>SE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Apple</td>
<td>Gala</td>
<td>Laboratory</td>
<td>Top</td>
<td>1.89 b</td>
<td>0.070</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Field</td>
<td>Top</td>
<td>0.03 d</td>
<td>0.003</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Laboratory</td>
<td>Bottom</td>
<td>3.43 a</td>
<td>0.114</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Field</td>
<td>Bottom</td>
<td>0.06 d</td>
<td>0.004</td>
</tr>
<tr>
<td>Peach</td>
<td>Encore</td>
<td>Laboratory</td>
<td>Top</td>
<td>1.27 c</td>
<td>0.061</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Field</td>
<td>Top</td>
<td>0.14 d</td>
<td>0.012</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Laboratory</td>
<td>Bottom</td>
<td>1.02 c</td>
<td>0.068</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Field</td>
<td>Bottom</td>
<td>0.15 d</td>
<td>0.013</td>
</tr>
<tr>
<td>Peach</td>
<td>Red Haven</td>
<td>Laboratory</td>
<td>Top</td>
<td>1.91 b</td>
<td>0.145</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Field</td>
<td>Top</td>
<td>0.07 d</td>
<td>0.005</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Laboratory</td>
<td>Bottom</td>
<td>1.95 b</td>
<td>0.222</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Field</td>
<td>Bottom</td>
<td>0.06 d</td>
<td>0.004</td>
</tr>
</tbody>
</table>

<sup>a</sup>F = 52; df = 2, 2358; P < 0.001.
<sup>a</sup>Means followed by the same letter are not significantly different (Fisher’s protected LSD, P < 0.05).

Table 3. Mean (±SE) microcapsule density on top and bottom ‘Gala’ and ‘Delicious’ apple leaves and ‘Encore’ and ‘Red Haven’ peach leaves after CheckMate® OFM-F microencapsulated pheromone was applied with an airblast sprayer at a rate of 86.6 mL of Checkmate® OFM-F in 378.5 L of water (2.93 fl. oz./100 gal.), Mountain Grove, Missouri, 2003.

<table>
<thead>
<tr>
<th>Tree</th>
<th>Cultivar</th>
<th>Leaf surface</th>
<th>Mean&lt;sup&gt;a&lt;/sup&gt;</th>
<th>SE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Apple</td>
<td>Gala</td>
<td>Top</td>
<td>0.021 e</td>
<td>0.002</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Bottom</td>
<td>0.076 a</td>
<td>0.007</td>
</tr>
<tr>
<td>Apple</td>
<td>Delicious</td>
<td>Top</td>
<td>0.015 e</td>
<td>0.002</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Bottom</td>
<td>0.062 b</td>
<td>0.005</td>
</tr>
<tr>
<td>Peach</td>
<td>Encore</td>
<td>Top</td>
<td>0.072 a</td>
<td>0.006</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Bottom</td>
<td>0.078 a</td>
<td>0.006</td>
</tr>
<tr>
<td>Peach</td>
<td>Red Haven</td>
<td>Top</td>
<td>0.052 c</td>
<td>0.003</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Bottom</td>
<td>0.038 d</td>
<td>0.002</td>
</tr>
</tbody>
</table>

<sup>a</sup>F = 7.05; df = 3, 18; P < 0.001.
<sup>a</sup>Means followed by the same letter are not significantly different (Fisher’s protected LSD, P < 0.05).
conducted to compare different fruit species using a field application method (e.g., airblast sprayer). However, factors such as tree size, leaf canopy density, and row spacing could be potentially confounding variables affecting the number of pheromone microcapsules on leaves.

The large differences between the number of microcapsules on laboratory-treated and field-treated leaves illustrate the distinction between these two application methods and environments. Laboratory leaf dips eliminate sprayer and environmental variables that can reduce coverage during airblast sprayer applications of microencapsulated pheromone. However, airblast sprayer applications are more realistic of a standard application in commercial orchards. As this study demonstrates, caution should be exercised when comparing leaf dip applications of microencapsulated pheromone in the laboratory to field applications using an airblast sprayer.

After an airblast sprayer application, only a fraction of the total number of pheromone microcapsules in a spray tank adheres to a leaf surface. Some of the microcapsules may come in contact with other tree tissues such as fruit, limbs, and the trunk, and some may contact nontarget plants on the orchard floor. The microcapsules that adhere to other tree tissues may still contribute to mating disruption, whereas, the microcapsules on the orchard floor may be less effective because oriental fruit moth mating occurs in the tree canopy. Knight & Larsen (2001) demonstrated that microencapsulated pheromone applied to the orchard floor was ineffective at disrupting mating of codling moth, *Cydia pomonella* L (Lepidoptera: Torticidae). A previous study indicated that 1-yr-old woody tissue and fruit had a significantly higher microcapsules density than mature leaves (Waldstein & Gut 2003). However, that study was conducted using laboratory plant tissue dips with a different formulation of microencapsulated pheromone than the one used in this study (i.e., OFM MEC Phase III, 3M Canada company, London, Ontario, Canada). Further studies should be conducted to determine if other tree fruit tissues have higher microcapsule density than leaves after an airblast sprayer application of microencapsulated pheromone. Another potential topic of future studies is the contribution of oriental fruit moth mating disruption by microcapsules that adhere to nontarget plant tissues on the orchard floor.

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