OPTIMIZATION OF SYNTHETIC PHEROMONE BLEND FOR USE IN MONITORING *CHORISTONEURA ROSACEANA* (LEPIDOPTERA: TORTRICIDAE) IN NIAGARA PENINSULA, ONTARIO, APPLE ORCHARDS

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Abstract

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Trapping experiments were carried out in Niagara peninsula, Ontario apple orchards to determine the optimum ratios of synthetic pheromone compounds for use in monitoring the obliquebanded leafroller, *Choristoneura rosaceana* (Harris) (Leptidoptera: Tortricidae). The mean total number of moths captured in traps baited with rubber stopper lures impregnated with 0.97 mg of the major compound (*Z*)-11-tetradecenyl acetate (*Z*11-14:OAc) increased 3–4-fold with the addition of 2% of the minor compound (*E*)-11-tetradecenyl acetate (*E*11-14:OAc) and increases to 4 and 8% did not change average catch. The addition of 1–8% of the minor compound (*Z*)-11-tetradecenol (*Z*11-14:OH) to lures containing 0.97 mg *Z*11-14:OAc + 2% *E*11-14:OAc did not affect average catch. There was a 3.5–3.8-fold increase in catch when 0.97 mg *Z*11-14:OAc + 2% *E*11-14:OAc + 1.5% *Z*11-14:OH was combined with 1% of the minor compound (*Z*)-11-tetradecenal (*Z*11-14:Ald). Mean trap catch declined when the relative amount of *Z*11-14:Ald was ≥4%. There was a 2.3–3.7-fold increase mean trap catch when 0.97 mg *Z*11-14:OAc + 1.5% mg *Z*11-14:OH + 1% *Z*11-14:Ald was combined with 1% *E*11-14:OAc. There was no increase in catch with additional increases in the relative amount of *E*11-14:OAc. There was a 1.8–2.3-fold decrease in catch when 2% *Z*11-14:OH was combined with 0.97 mg *Z*11-14:OAc + 2% *E*11-14:OAc + 1% *Z*11-14:Ald. There was no change in mean trap catch with the addition of greater relative amounts of *Z*11-14:OH. The results suggest that the optimum blend of synthetic pheromone compounds for use in monitoring *C. rosaceana* in the Niagara peninsula of Ontario is a blend of the main compound *Z*11-14:OAc plus the minor compounds in relative amounts of 1% *E*11-14:OAc, 0–1% *Z*11-14:OH and 1% *Z*11-14:Ald.

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Introduction

The obliquebanded leafroller, *Choristoneura rosaceana* (Harris) (Lepidoptera: Tortricidae), is native to North America where it is distributed throughout southern Canada and most areas of the continental United States, except the arid southwest (Chapman and Lienk 1971). The larvae of *C. rosaceana* are polyphagous, feeding on the foliage and fruit of many deciduous plants, although its primary hosts typically belong to the Rosaceae (Weires and Riedl 1991). There are one or two generations per year, depending on climate, and second- or third-instar larvae overwinter in a hibernaculum (Chapman and Lienk 1971). *Choristoneura rosaceana* is a key pest of commercial apple, *Malus domestica* (Borkh) (Rosaceae) in Ontario where sprays of insecticide are applied to control the larvae of its two annual generations (Anonymous 2009, 2010).

The sex pheromone of *C. rosaceana* consists of the major compound (*Z*)-11-tetradecenyl acetate (*Z*11-14:OAc) (Roelofs and Tette 1970) and three minor compounds, (*E*)-11-tetradecenyl acetate (*E*11-14:OAc), (*Z*)-11-tetradecenol (*Z*11-14:OH) and (*Z*)-11-tetradecenal (*Z*11-14:Ald) (Cardé et al. 1977; Hill and Roelofs 1979; Vakenti et al. 1988; El-Sayed et al. 2001*a*). It was initially believed that *Z*11-14:Ald was present only in populations from western North America (Vakenti et al. 1988; Thomson et al. 1991), but further investigation revealed that this compound was also an important component of the pheromone of some eastern North American populations of this species in Ontario and Quebec (El-Sayed et al. 2001*a*, 2003). The pheromone gland and effluvium of an Ontario population of *C. rosaceana* contained approximately 96% *Z*11-14:OAc, 2% *E*11-14:OAc, 1.5% *Z*11-14:OH and 0.5% *Z*11-14:Ald (El-Sayed et al. 2001*ab*).

Traps baited with synthetic sex pheromone are used to accurately time insecticide sprays for the control of *C. rosaceana* in Ontario apple orchards (Anonymous 2009). Sex pheromone-baited traps have also been used in Ontario to indirectly measure the effectiveness of pheromone treatments applied to control *C. rosaceana* by sex pheromone-mediated mating disruption (Trimble and Appleby 2004). Field trapping studies carried out in the Niagara peninsula of Ontario have demonstrated the behavioral activity of the minor pheromone compounds when combined with the main compound in relative amounts of 2% (*E*11-14:OAc), 1.5% (*Z*11-14:OH) and 1% (*Z*11-14:Ald) (El-Sayed et al. 2001*a*, 2003; Trimble and Marshall 2008), but it is not known if this is the optimal blend of compounds for use in this location. This paper reports the results of field trapping experiments designed to determine if the previously used blend is optimal for use in apple orchards in the Niagara peninsula of Ontario.

Materials and Methods

Synthetic pheromone

Pheromone compounds were acquired from the Pherobank, Plant Research International, Wageningen, The Netherlands. The *Z*11-14:OAc was 99.2% chemically pure and contained 0.4% *E*11-14:OAc. It did not contain the known *C. rosaceana* attraction inhibitors (*Z*)-9-tetradecenyl acetate (*Z*9-14:OAc) or (*E*)-9-tetradecenyl acetate (*E*9-

14:OAc) (Trimble and El-Sayed 2006). The *E*11-14:OAc had a chemical and isomeric purity of 99.5%. The *Z*11-14:OH and *Z*11-14:Ald had a chemical purity of 99 and 91.5%, respectively.

Field trapping experiments

A stepwise approach was used to determine the effect on trap catch of combining increasing relative amounts of minor compounds with the main pheromone compound. In the first experiment, *Z*11-14:OAc was combined with 0, 1, 2, 4 or 8% *E*11-14:OAc. In the second experiment *Z*11-14OAc + 2% *E*11-14:OAc was combined with 0–8% *Z*11-14:OH. In the third experiment *Z*11-14OAc + 2% *E*11-14:OAc + 1.5% *Z*11-14:OH was combined with 0–8% *Z*11-14:Ald. In a second set of experiments, *Z*11-14OAc + 1.5% *Z*11-14:OH + 1% *Z*11-14:Ald was combined with 0–8% *E*11-14:OAc, and *Z*11-14OAc + 2% *E*11-14:OAc + 1% *Z*11-14:Ald was combined with 0–8% *Z*11-14:OH. Trap lures were prepared by applying 200 µl of pheromone in hexane, or hexane (i.e. control), to the large "well" of 9 mm diameter, natural rubber sleeve stoppers (Chromatographic Specialties, Brockville, Ontario). The solvent was allowed to evaporate in a fume hood and the stoppers were stored at –20°C until use. Stoppers were attached to 8 mm-diameter corks using an insect pin. The corks were positioned in the middle of the insect adhesive-coated surface of 21 cm-long x 20 cm-wide x 12 cm-high white plastic delta traps (Cooper Mill Ltd., Madoc, Ontario) and the traps were positioned 1.5–2.0 m above the ground within the tree canopy.

Experiments were carried out in 0.2–2.2 ha plots of cv. Empire, McIntosh or Red Delicious insecticide-free apple trees at the Agriculture and Agri-Food Canada (AAFC) Experimental Farm at Jordan Station, Ontario (43°10′N 79°24′W) during the first and second annual *C. rosaceana* flights of 2004–2008, and during each of the two annual flights of 2010. A randomized complete block (RCB) or split-plot experimental design (Snedecor and Cochran 1989) was used to test the effect of varying the relative amounts of *E*11-14:OAc and *Z*11-14:OH (2004–2008). The location of treatments within blocks (RCB) or subplots (split-plot) was not changed during a flight period. There was ≈10 m between traps. A completely randomized design (Snedecor and Cochran 1989) was used to test the effect of varying the relative amount of *Z*11-14:Ald (2010). There was ≈20 m between traps in this experiment and the location of treatments was re-randomized at 14 d intervals. In all experiments moths were counted and removed from the traps twice each week and the rubber stopper lures were renewed at 2-wk intervals.

Analysis of data

Statistical analyses were performed using JMP® 7.0 (SAS Institute, Cary, North Carolina). The significance of the effect of the relative amount of a minor compound on the mean number of moths captured during a flight was tested using a randomized complete block, split-plot, or completely randomized analysis of variance model after transforming the data using $\sqrt{(x + 0.5)}$. The significance of differences between means was first tested using the Tukey Honestly Significant Difference (HSD) test. If there were no differences using this test the Fisher Least Significant Difference (LSD) test was used to identify differences (Dallal 2001). Means were back-transformed for presentation in tables (Snedecor and Cochran 1989).

Results

The attractiveness of lures baited with *Z*11-14:OAc was increased by the addition of *E*11-14:OAc (Table 1). There was a 3- and 4-fold increase in the mean total number of moths captured during the spring and summer flights of 2004, respectively, when 0.97 mg of *Z*11-14:OAc was combined with 0.02 mg *E*11-14:OAc (2%). There was no statistically detectable increase in trap catch when the relative amount of *E*11-14:OAc was 1%, and increases above 2% did not significantly change average catch (Table 1). The addition of *Z*11-14:OH to lures containing a blend of 0.97 mg *Z*11-14:OAc + 0.02 mg *E*11-14:OAc (2%) did not affect the mean total number of moths captured during the spring and summer flights of 2005 (Table 2). There was a 3.5- and 3.8-fold increase in the mean total number

TABLE 1. Mean ± SD total number *Choristoneura rosaceana* captured in traps baited with lures containing a constant amount of *Z*11-14:OAc and increasing amounts of *E*11-14:OAc.

Treatment	Amount of compound, mg/lure		Total number captured	
	*Z*11-14:OAc	*E*11-14:OAc	First flight	Second Flight
1	0.97	0.0	5.4±3.4b (29)	8.5±8.7b (50)
2	0.97	0.01	10.6±11.6ab (64)	22.0±30.6ab (134)
3	0.97	0.02	14.6±17.3a (89)	32.8±51.8a (211)
4	0.97	0.04	8.7±7.2ab (48)	22.3±18.1ab (123)
5	0.97	0.08	6.9±7.4ab (40)	24.5±23.2ab (147)
6	0.0	0.0	0.0±0.0c (0)	0.0±0.0c (0)

Total number trapped in parenthesis. First flight, 11 June – 9 July 2004 (n = 270), RCB ANOVA, F = 6.21, df = 5,20, P = 0.0013; Second flight, 4 August – 16 September 2004 (n = 665), RCB ANOVA, F = 6.47, df = 5,20, P = 0.001. Means within each flight followed by the same letter not significantly different (Fisher LSD test, P > 0.05).

TABLE 2. Mean ± SD total number *Choristoneura rosaceana* captured in traps baited with lures containing constant amounts of *Z*11-14:OAc and *E*11-14:OAc and increasing amounts of *Z*11-14:OH.

Treatment	Amount of compound, mg/lure			Total moths captured	
	*Z*11-14:OAc	*E*11-14:OAc	*Z*11-14:OH	First flight	Second flight
1	0.97	0.02	0.0	11.2±8.2a (61)	13.0±23.3a (374)
2	0.97	0.02	0.01	10.3±7.3a (56)	10.7±26.4a (348)
3	0.97	0.02	0.02	8.9±10.6a (52)	5.4±17.0a (193)
4	0.97	0.02	0.04	13.9±17.2a (82)	11.0±35.6a (355)
5	0.97	0.02	0.08	11.6±8.9a (63)	8.6±27.1a (283)
6	0.0	0.0	0.0	0.0±0.0b (0)	0.0±0.0b (0)

Total number trapped in parenthesis. First flight, 13 June – 11 July 2005 (n = 314), RCB ANOVA, F = 12.92, df = 5,20, P < 0.0001); Second flight, 29 July – 21 September 2005 (n = 1554), Split-plot ANOVA, F = 4.78, df = 5,60, P < 0.008. Means in a column within each flight followed by the same letter not significantly different (Fisher LSD test, P > 0.05).

of moths captured during the spring and summer flights of 2010, respectively, when a blend of 0.97 mg *Z*11-14:OAc + 0.02 mg *E*11-14:OAc (2%) + 0.015 mg *Z*11-14:OH (1.5%) was combined with 0.01 mg (1%) of *Z*11-14:Ald (Table 3). Mean trap catch declined when the relative amount of *Z*11-14:Ald was increased to 4% during the spring flight and to 8% during the summer flight. There was a 2.3- and 3.7-fold increase in the mean total number of moths captured during the spring and summer flights of 2006, respectively, when a blend of 0.97 mg *Z*11-14:OAc + 0.015 mg *Z*11-14:OH (1.5%) + 0.01 mg *Z*11-14:Ald (1%) was combined with 0.01 mg (1%) of *E*11-14:OAc (Table 4). There was no increase in mean trap catch with additional increases in the relative amount of *E*11-14:OAc. There was no change in the mean total number of moths captured during the spring and summer flights of 2007 when 0.01 mg *Z*11-14:OH (1%) was combined with a blend of 0.97 mg *Z*11-14:OAc + 0.02 mg *E*11-14:OAc (2%) + 0.01 mg *Z*11-14:Ald (1%). There was a 1.8- and 2.3-fold decrease in the mean total number of moths captured during these flights, however, when 0.02 mg *Z*11-14:OH (2%) was used in this blend (Table 5). There was no change in mean trap catch with the addition of greater relative amounts of *Z*11-14:OH.

TABLE 3. Mean ± SD total number *Choristoneura rosaceana* captured in traps baited with lures containing constant amounts of *Z*11-14:OAc, *E*11-14:OAc and *Z*11-14:OH and increasing amounts of *Z*11-14:Ald.

Treatment	Amount of compound, mg/lure				Total moths captured	
	*Z*11-14:OAc	*E*11-14:OAc	*Z*11-14:OH	*Z*11-14:Ald	First flight	Second flight
1	0.97	0.02	0.015	0.0	26.0±18.5c (113)	7.4±1.7c (30)
2	0.97	0.02	0.015	0.01	90.9±28.8ab (371)	28.2±8.3a (115)
3	0.97	0.02	0.015	0.02	95.5±34.5a (390)	18.0±1.8ab (72)
4	0.97	0.02	0.015	0.04	30.8±15.2c (128)	16.7±7.2abc (69)
5	0.97	0.02	0.015	0.08	41.3±16.2bc (170)	13.8±6.7bc (57)
6	0.0	0.0	0.0	0.0	0.8±1.2d (4)	0.4±1.0d (2)

Total number trapped in parenthesis. First flight, 27 May – 8 July 2010 (n = 1176), One-way ANOVA, F = 20.92, df = 5,18, P < 0.0001; Second flight, 27 July – 13 September 2010 (n = 345), One-way ANOVA, F = 23.40, df = 5,18, P < 0.0001. Means in a column within each flight followed by the same letter not significantly different (Tukey HSD test, P > 0.05).

Discussion

The results of this study suggest that the optimum blend of synthetic pheromone compounds for use in monitoring *C. rosaceana* in the Niagara peninsula of Ontario is a blend of the main compound *Z*11-14:OAc plus the minor compounds in relative amounts of 1% *E*11-14:OAc, 0–1% *Z*11-14:OH and 1% *Z*11-14:Ald. Traps baited only with the main compound required the addition of 2% *E*11-14:OAc to effect a significant increase in the capture of moths, but when traps were baited with the main compound and each of the three

TABLE 4. Mean ± SD total number *Choristoneura rosaceana* captured in traps baited with lures containing constant amounts of *Z*11-14:OAc, *Z*11-14:OH and *Z*11-14:Ald and increasing amounts of *E*11-14:OAc.

Treatment	Amount of compound, mg/lure				Total moths captured	
	*Z*11-14:OAc	*E*11-14:OAc	*Z*11-14:OH	*Z*11-14:Ald	First flight	Second flight
1	0.97	0.00	0.015	0.01	9.1±7.7b (51)	16.7±23.7b (105)
2	0.97	0.01	0.015	0.01	21.3±17.2a (121)	62.2±51.2a (352)
3	0.97	0.02	0.015	0.01	17.5±9.7ab (93)	53.8±33.8a (291)
4	0.97	0.04	0.015	0.01	23.0±13.6a (100)	75.8±65.7a (423)
5	0.97	0.08	0.015	0.01	12.9±7.7ab (69)	48.9±25.1a (257)
6	0.0	0.0	0.0	0.0	0.0±0.0c (0)	0.0±0.0c (0)

Total number trapped in parenthesis. First flight, 9 June – 19 July 2006 (n = 434), RCB ANOVA, F = 11.39, df = 5,20, P < 0.0001; Second flight, 31 July – 10 October 2006 (n = 1428), RCB ANOVA, F = 14.21, df = 5,20, P = 0.0001. Means in a column within each flight followed by the same letter not significantly different (Fisher LSD test, P > 0.05).

TABLE 5. Mean ± SD total number *Choristoneura rosaceana* captured in traps baited with lures containing constant amounts of *Z*11-14:OAc, *E*11-14:OAc and *Z*11-14:Ald and increasing amounts of *Z*11-14:OH.

Treatment	Amount of compound, mg/lure				Total moths captured	
	*Z*11-14:OAc	*E*11-14:OAc	*Z*11-14:OH	*Z*11-14:Ald	First flight	Second flight
1	0.97	0.02	0.0	0.01	28.5±28.7a (502)	14.7±13.4a (273)
2	0.97	0.02	0.01	0.01	22.6±18.9ab (383)	9.8±6.0ab (169)
3	0.97	0.02	0.02	0.01	15.9±19.9b (282)	6.4±4.3b (110)
4	0.97	0.02	0.04	0.01	13.0±12.9b (225)	5.2±5.9b (103)
5	0.97	0.02	0.08	0.01	15.2±10.3b (251)	8.5±7.9ab (160)
6	0.0	0.0	0.0	0.0	0.1±0.5c (2)	0.2±0.4c (4)

Total number trapped in parenthesis. First flight, 6 June – 18 July 2007 (n = 1645), Split-plot ANOVA, F = 14.90, df = 5,40, P = 0.0002; Second flight, 23 July – 3 October 2007 (n = 819), Split-plot ANOVA, F = 12.90, df = 5,40, P = 0.0004. Means in a column within each flight followed by the same letter not significantly different (Fisher LSD test, P > 0.05).

minor compounds, the inclusion of *E*11-14:OAc at 1% was sufficient to effect a significant increase in the capture of *C. rosaceana*. There was no increase in the number of moths captured with the use of greater relative amounts of *E*11-14:OAc in the complete, four-compound blend.

The results suggest that it may not be necessary to include *Z*11-14:OH in synthetic *C. rosaceana* pheromone for use in the Niagara peninsula because there was no change in the number of moths captured in traps baited with *Z*11-14:OAc plus 2% *E*11-14:OAc when *Z*11-14:OH was included at 1, 2, 4 or 8% relative to the main compound. In addition, there was no change in the number of moths captured when 1% *Z*11-14:OH was added to a blend of *Z*11-14:OAc plus relative amounts of 2% *E*11-14:OAc and 1% *Z*11-14:Ald; the addition of greater relative amounts of *Z*11-14:OH to this blend significantly reduced the number of moths captured compared to the numbers captured in traps baited with a lure that did not contain the alcohol. In another field trapping study conducted in Niagara peninsula apple orchards, Trimble and Marshall (2008) were unable to detect any increase in trap catch during three of four *C. rosaceana* flight periods when 1.5% Z11-14:OH was added to a blend of Z11-14:OAc plus 2% E11-14:Ac; however, during a fourth flight period there was a 2.2-fold increase in trap catch with the addition of the alcohol.

The pheromone gland of female *C. rosaceana* from the Niagara peninsula contained *Z*11-14:OH in amounts ranging from 1.16–2.20% relative to the main pheromone compound *Z*11-14:OAc (El-Sayed et al. 2001*ab*, 2003; El-Sayed and Trimble 2002) and the pheromone gland effluvium contained 1.75% *Z*11-14:OH relative to the main pheromone compound (El-Sayed et al. 2001*b*). In addition, the electroantennogram (EAG) response–pheromone dose relationships measured in the antennae of male *C. rosaceana* from the Niagara peninsula was similar for *Z*11-14:OAc and *Z*11-14:OH (El-Sayed et al. 2001*b*). The production and emission of *Z*11-14:OH by female *C. rosaceana*, and the ability of male antennae to detect this compound suggests that it has a role in the pheromone-mediated sexual communication of Niagara populations of this species. In a flight tunnel experiment using male *C. rosaceana* from the Niagara peninsula, there was a trend of increase in the proportion of individuals initiating the take-off, lock-on, close-in, and touchdown phases of upwind flight to *Z*11-14:OAc when *E*11-14:OAc, *Z*11-14:OH and *Z*11-14:Ald were successively added in relative amounts of 2, 1.5 and 1%, respectively (Trimble and Marshall 2008). This observation suggests that *Z*11-14:OH is important in the chemical communication of *C. rosaceana* and should be included in a blend of synthetic pheromone compounds for use in monitoring the presence and activity of this species in the Niagara peninsula.

The results of the present study confirm the behavioural activity of the minor pheromone compound *Z*11-14:Ald. There was an approximately 4-fold increase in the capture of *C. rosaceana* in traps baited with *Z*11-14:OAc plus relative amounts of 2% *E*11-14:OAc and 1.5% *Z*11-14:OH when 1% *Z*11-14:Ald is added to the blend. In previous trapping studies in Niagara peninsula apple orchards 2–3-fold increases in trap catch were observed after the addition of 1% of the aldehyde compound (El-Sayed et al. 2001*a*, 2003; Trimble and Marshall 2008).

The significance of differences between the mean numbers of *C. rosaceana* captured in traps baited with different blends of pheromone was tested using both the Tukey HSD test and the Fisher LSD test. The Tukey HSD test is very conservative, i.e. it has a low

likelihood of declaring differences when none exist, whereas the Fisher LSD test is liberal, i.e. it has a higher likelihood of declaring differences when none exist (Chew 1976). The approach recommended by Dallal (2001) was used to test for the significance of differences between the mean numbers of *C. rosaceana* captured in traps baited with difference blends of synthetic pheromone compounds. The Tukey HSD was first applied and significant differences were accepted. If no differences were found using the Tukey HSD test, the significance of differences between means was then tested using the Fisher LSD test. Dallal (2001) advised that differences judged significant by the Fisher LSD test but not by the Tukey HSD test should be considered open to further investigation. In the present study, the Tukey HSD test identified differences between means only in the experiment where the relative amount of *Z*11-14:Ald was varied in a blend of *Z*11-14:OAc plus 2% *E*11-14:OAc and 1.5% *Z*11-14:OH. This suggests that additional experimentation should be undertaken to confirm the results of the other experiments carried out in this study. The use of a flight tunnel for these studies would eliminate the need to control for possible trap position effects and would permit between-experiment uniformity of sample size. Flight tunnel experiments, however, might not yield pheromone-blend differences that are detectable using a conservative multiple comparison test like the Tukey HSD. For example, Trimble and Marshall (2008) did not detect an increase in the number of *C. rosaceana* males landing at a pheromone source in a flight tunnel when 2% Z11-14:Ald was added to a blend of *Z*11-14:OAc plus 2% *E*11-14:OAc and 1.5% *Z*11-14:OH, whereas in the currently reported field trapping study, a 2.4–3.7-fold increase in the capture of *C. rosaceana* was detected with the addition of 2% of the aldehyde to this blend of compounds.

There is evidence of geographic variation in the optimum ratio of the main pheromone compound and its *E*-isomer. For example, in New York apple orchards, Hill and Roelofs (1979) found that traps baited with the main compound required the addition of at least 3% *E*11-14:OAc to significantly increase the capture of *C. rosaceana*. They also found no difference in the number of moths captured when using relative amounts of *E*11-14:OAc ranging from 3–12%; in their study the number of trapped moths declined when the relative amount of *E*11-14:OAc exceeded 12%. In a Quebec woodlot, Delisle (1992) found that during the first annual flight of *C. rosaceana* traps baited with *Z*11-14:OAc plus 10% *E*11-14:OAc captured more *C. rosaceana* than traps baited with *Z*11-14:OAc plus 3% *E*11-14:OAc; these blends captured similar numbers of moths during the second flight of the year. In Michigan apple orchards, traps baited with the main pheromone compound plus 5% *Z*11-14:OH and 2% *Z*11-14:Ald captured more *C. rosaceana* when *E*11-14:OAc was included at 4% compared to when this compound was included at 1 or 10%, whereas in Oregon apple orchards, the addition of *E*11-14:OAc at 1% resulted in the capture of a greater number of *C. rosaceana* than when this compound was added at 4 or 10% (Stelinski et al. 2007).

There is also evidence of geographic variation in the behavioural activity of *Z*11-14:OH when used as a component of synthetic pheromone for monitoring *C. rosaceana*. For example, in New York apple orchards, Hill and Roelofs (1979) found statistically similar increases of 1.5–2.2-fold in the capture of *C. rosaceana* when 0.5–5% *Z*11-14:OH was added to a two compound blend of *Z*11-14:OAc plus 3% *E*11-14:OAc. In Quebec, Delisle (1992) found that the capture of *C. rosaceana* increased in traps baited with *Z*11-14:OAc plus 2% *E*11-14:OAc when *Z*11-14:OH was added at 1.5% relative to *Z*11-14:OAc, and

as well in traps baited with *Z*11-14:OAc plus 5.6 % *E*11-14:OAc when *Z*11-14:OH was added at 5.6% relative to *Z*11-14:OAc. In Michigan apple orchards, traps baited with the main pheromone compound plus 4% *E*11-14:OAc and 2% *Z*11-14:Ald captured similar numbers of *C. rosaceana* when *Z*11-14:OH was included at 1, 4 and 10% relative to the main compound (Stelinski et al. 2007). In Oregon apple orchards during the first annual flight, the addition of *Z*11-14:OH to the three compound blend used in Michigan at 1% and 4% resulted in similar trap catches of *C. rosaceana*, but trap catch was reduced when the alcohol compound was included at 10% relative to the main compound; trap catch was greatest using 1% *Z*11-14:OH during the second flight period in Oregon (Stelinski et al. 2007).

Geographic variation in the behavioural activity of *Z*11-14:Ald has been previously reported for *C. rosaceana*. The pheromone gland of populations from British Columbia, Michigan, Ontario, Quebec, New York (El-Sayed et al. 2003) and from Oregon (Stelinski et al. 2007) contained *Z*11-14:Ald, and the inclusion of this compound in traps baited with *Z*11-14:OAc, *E*11-14:OAc and *Z*11-14:OH resulted in significant increases in the capture of moths in all of these locations except Michigan (El-Sayed et al. 2003; Stelinski et al. 2007) and New York (El-Sayed et al. 2003). The addition of *Z*11-14:Ald to traps baited with *Z*11-14:OAc, *E*11-14:OAc and *Z*11-14:OH also significantly increased trap catch of *C. rosaceana* in Minnesota apple orchards (Fadamiro 2004). The current study provides additional information on geographic variation in the behavioural activity of *Z*11-14:Ald in *C. rosaceana*. In Niagara apple orchards, there was no change in the number of moths trapped when the relative amount of *Z*11-14:Ald was increased from 1 % to 2%, but trap catch declined when the amount was increase to 4% during the first flight, and to 8% in the second annual flight. In a previous trapping study in Niagara peninsula apple orchards, the capture of *C. rosaceana* declined when the relative amount of *Z*11-14:Ald was increased from 4 to 8% (El-Sayed et al. 2003). By contrast, in British Columbia apple orchards, Vakenti et al. (1988) found no change in the number of *C. rosaceana* captured in traps baited with *Z*11-14:OAc plus 2% *E*11-14:OAc and 1.5% *Z*11-14:OH when *Z*11-14:Ald was added at 2, 4 and 8% relative to *Z*11:14:OAc. Similarly, in Oregon apple orchards, traps baited with the main pheromone compound plus 4% *E*11-14:OAc and 5% *Z*11-14:OH captured similar numbers of *C. rosaceana* when *Z*11-14:Ald was included at 4 and 10% (Stelinski et al. 2007).

In addition to the relative amounts of minor compounds in synthetic pheromone, pheromone dose and formulation can also affect the performance of a synthetic sex-pheromone lure (Wall 1989). In the present study, rubber stoppers were loaded with 1 mg of pheromone but it is not known if this resulted in optimal attractiveness under the conditions in which the effectiveness of different pheromone blends was compared. In British Columbia, Vakenti et al. (1988) found that traps baited with lures loaded with 3 mg of an optimally attractive blend captured 13x more *C. rosaceana* than traps baited with 0.3 mg of the same blend of compounds. The use of the optimally attractive pheromone load in a lure could be important when monitoring small populations of *C. rosaceana*, and therefore additional research should be carried out to determine the relationship between pheromone load and trap catch for this pest in Niagara peninsula apple orchards.

The amount of pheromone loaded into a stopper could also affect its longevity. In the present study the rubber stopper lures were renewed every two weeks during the

4–6 week flight period of *C. rosaceana* in to an attempt to compensate for a change in their attractiveness due to the loss of pheromone, or to a change in the ratio of pheromone compounds. Additional research should also be undertaken to determine the rate of decline in attractiveness of lures to insure that reductions in trap catch are the result of declines in population density and not lure attractiveness.

Sex-pheromone lures can be formulated using rubber, polyethylene or polyvinyl chloride, and the material used to control the release of pheromone will also affect the longevity of a lure (Wall 1989). In addition, the formulation material can also affect the stability of pheromone compounds. For example, McDonough (1991) found that aldehyde pheromone compounds were susceptible to oxidation when formulated on rubber substrates. In British Columbia however, Vakenti et al. (1988) found that the addition of an antioxidant compound to natural rubber lures loaded with *Z*11-14:OAc plus 2% *E*11-14:OAc, 1.5% *Z*11-14:OH and 1% *Z*11-14:Ald had no effect on the number of *C. rosaceana* captured after 10 weeks of field use. This suggests that oxidation of *Z*11-12:Ald should not be a contributing factor to a decline in lure attractiveness when *C. rosaceana* synthetic pheromone is loaded into natural rubber sleeve stoppers.

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