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Mating disruption of codling moth with a continuous adhesive tape carrying high densities of pheromone dispensers

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Abstract

A new mating disruption approach, EcoTape FTF, has been recently developed for codling moth *Cydia pomonella* (L.) control. EcoTape is a continuous adhesive tape (500 or 625 m long, 1 cm wide) with dispensers (3-cm length and each with 2.5 mg codlemone) at 0.6 m spacing. The tape is unrolled through the canopy row providing high densities of sex pheromone dispensers (from 2,000 to 5,000 dispensers/ha). The release rate of new and field-aged dispensers, measured by solid-phase micro-extraction (SPME), decreased over time but at the end of the season individual dispensers still emitted more codlemone than the amount reported for a codling moth calling female. Single dispensers elicited close-range approaches and touchings by males in a wind tunnel. In the field, traps containing aged EcoTape dispensers captured similar numbers of males throughout the season to traps containing standard monitoring rubber septum lures. The attractiveness both in wind tunnel and in the field suggests that EcoTape dispensers may satisfy some of the prerequisites for producing a false-trail following (FTF) effect on *C. pomonella* males. The results of field trials (2004-2007) demonstrated that the application of EcoTape can control codling moth throughout the season under the climatic conditions of northern Italy with an efficacy comparable with those of conventional strategies based on chemicals and pheromones.

Key words: E8,E10-dodecadien-1-ol, *Cydia pomonella*, EcoTape, competitive attraction, wind tunnel, field test, field aged dispensers.

Introduction

Control of the codling moth (CM) *Cydia pomonella* (L.) (Lepidoptera Tortricidae), the major pest in pome fruit orchards, relies largely on insecticide application, which harms beneficials, selects for pesticide resistance, and causes environmental problems (Blommers, 1994; Charmillot *et al.*, 2003). Furthermore, deregulation of several toxic insecticides by the European Union has increased the need for alternative control strategies. The most common environmentally safe method for managing CM is pheromone-based mating disruption (MD), with ca. 160,000 ha of treated crop worldwide (Witzgall *et al.*, 2008). MD commonly uses 300 to 1,000 reservoir dispensers/ha, each loaded with 130-270 mg of pheromone. The efficacy of this technique, however, is not always satisfactory, especially when CM numbers are high or the treated area is small (Cardé and Minsk, 1995). An important limitation to implementing MD is that the mechanisms proposed are several (Bartell, 1982; Cardé, 1990; Sanders, 1996), and they are largely circumstantial and vary with pest species, pheromone dose and characteristics, dispenser performance, environment, crop structure, and pest population density (Arn, 1992; Witzgall *et al.*, 2008). In particular, the mechanisms acting in the MD of CM with common hand-applied dispensers were presumed to result from a range of physiological and/or behavioural effects, such as competition, adaptation, habituation and camouflage acting alone, sequentially or in combination (Miller *et al.*, 2006; Maini, 2007).

Many investigations have been conducted to optimize MD for CM, and several have focussed on developing strategies based on timed pheromone-dispensing device (Maini *et al.*, 2006), high densities of sex pheromone dispensers or multiple female-equivalent sources (Knight and Larsen, 2004; Stelinski *et al.*, 2005; Epstein *et al.*, 2006; Angeli *et al.*, 2007; Stelinski *et al.*, 2008). The success of the two latter MD approaches relies greatly on the competitive behavioural mechanism, called also false-trail following (FTF), which probably depends on three factors: each dispenser should be as or more attractive than a calling female moth; there must be enough dispensers to make the probability of a male finding a female instead of a synthetic source very low; and the males must spend sufficient time going to the dispensers to further decrease the chance of finding calling females (Sanders, 1996; Miller *et al.*, 2006). Therefore, the number of required dispensers depends on the density of females, even though there is a density threshold above which we can not expect satisfactory efficacy from the application of this control method (Waldner, 2005).

The present work is aimed at characterizing a new MD approach, EcoTape® FTF, for control of CM. EcoTape consists of a continuous adhesive tape carrying a pheromone point source located every 60 cm. Each dispenser is loaded with 2.5 mg codlemone, and when the tape is strung through the orchard canopy, dispensers are applied at high densities (from 2,000 to 5,000 dispensers/ha). Compared to MD with other hand-applied dispensers, EcoTape contains a greatly reduced pheromone content per pheromone point source but many more point sources per ha; the purpose is to substantially increase the ratio of artificial to natural sources and thereby decrease the probability that males will find females. Laboratory and field trials were performed to: 1) calculate the release rate and life span of new and field-aged dispensers using solid-phase micro-extraction (SPME); 2) evaluate the attractiveness of the pheromone point sources toward CM males with both behavioural bioassays in a wind tunnel and field trapping experiments; 3) determine, over a 4-year period, the efficacy of the EcoTape device in preventing CM damage in growers' orchards.

Materials and methods

Insects

For laboratory trials, CM pupae were obtained from a mass-reared laboratory culture (Terremerse, Ravenna, Italy). Pupae were sexed and housed individually in plastic Petri dishes (diameter 5 cm) under a L16:D8 photoperiod at 23 ± 2 °C and 70 ± 5% R.H. Adults were fed on a cotton pad soaked in 10% sucrose solution (w/v sucrose in water). For the behavioural experiment, 2- to 3-day-old males were used.

Dispensers

The EcoTape FTF device (Certis, Saronno, Italy) consists of a continuous adhesive tape, 1 cm wide and 500 or 625 m long, with a 3-cm-long pheromone dispenser, located every 0.6 m along the length. Each dispenser is loaded with 2.5 mg of E,E-8,10-dodecadien-1-ol (E8,E10-12OH) and is formed by a three-layer laminate structure composed of a semi-permeable upper layer, a pheromone reservoir in the middle, and an impermeable backing layer. The tape is attached by hand to the upper third of the tree canopy and is unreeled along the entire length of the row.

Field ageing of dispensers

In 2006, EcoTape dispensers were applied once (11 May) in an experimental apple orchard of IASMA Research Center (Borgo Valsugana, 419 m a.s.l., 46°3'N - 11°27'E, Trento, Italy), before the beginning of the first CM flight in Trento Province (Schmidt *et al.*, 2006). For release rate analysis and behavioural bioassays, field-aged dispensers were collected weekly from the application time until the end of the season (8 September 2006) and stored at −20°C.

Release rate of dispensers

SPME in static air (Borg-Karlson and Mozuraitis, 1996) was used to evaluate pheromone release rate of the dispensers. The method for quantifying the dispenser emission by SPME was previously determined (Anfora *et al.*, 2005) and then adapted to E8,E10-12:OH (Angeli *et al.*, 2007). Chemical analyses were performed on a Hewlett-Packard 5890 GC, with a polar Innowax column (30 m x 0.32 mm; J & W Scientific, Folsom, CA, USA) programmed from 60 °C (hold 3 min) at 8 °C/min to 220 °C (hold 7 min).

Before analysis, dispensers were allowed to equilibrate for 24 h in a climatic chamber (25 ± 2 °C and 60 ± 5% R.H.). Each dispenser was cut from the tape and then individually sealed in a vial (2 ml) for volatile collection (n = 10). The SPME needle was inserted into the vial by piercing its Teflon® septum. Based on the previously recorded recovery rates, extraction (60 min) was preceded by 10 min of equilibration. The SPME fibre was then injected into the GC. The release rates of the dispensers were measured three times, with intervals of 15 days, during two distinct periods 0-30 and 85-115 days after the application, corresponding to the first and second CM flight, respectively, in Trento Province.

Wind tunnel bioassay

Responses elicited by a single EcoTape dispenser were measured after dispensers had been exposed in the field for 0, 15, 30, 85, 100, and 115 days. Data were compared with those obtained with a standard monitoring plastic vial loaded with 1 mg E8,E10-12:OH (AgriSense, Pontypridd, UK). Wind tunnel sessions started 1 h after the onset of scotophase and continued for 2 h. The bioassay was carried out using the glass wind tunnel and the method described by Angeli *et al.* (2007). The pheromone dispenser was hung vertically from a metal holder 10 cm from the upwind end of the tunnel in the middle of the cross section. Charcoal-filtered air flow was maintained at 0.15 m/sec, and red neon lights from above the tunnel provided 4.0 lux, enough to make behavioural observations. The tunnel was maintained at 22 ± 3 °C and 50-60% R.H. Virgin 2- to 3-day-old males (n = 20) were individually released from a glass tube (15 cm long x 2.5 cm diameter; open ends covered with rigid gauze) placed 150 cm downwind from the source. Males were allowed to respond for 15 min. Three behavioural sequences were recorded: activation (walking and wing-fanning); oriented upwind flight until 10 cm from the source; and contacts, both touchings and landings.

Field trapping

The attractiveness of EcoTape dispensers as they aged in the field was evaluated during 2006 in an untreated apple orchard (Borgo Valsugana). Sticky traps (Pomotrap®, Isagro, Novara, Italy) (Accinelli *et al.*, 1998) were baited with a single EcoTape dispenser and placed in the field on 11 May. To assess the effect of the trap covering in protecting EcoTape dispenser from the environment, dispensers were placed in traps after exposing them without protection in the plant canopy for different periods. Three treatments were compared. A new dispenser was placed in the trap and: 1) left there until the end of the season; 2) replaced every 14 days with one aged in the tree canopy; 3) replaced every 30 days with one aged in the tree canopy.

In all trials, three sticky traps baited with a standard pheromone lure (1 mg E8,E10-12:OH replaced every 42 days, Isagro) were used as references. Trap captures were checked weekly, and the number of males per trap per year was determined.

Evaluation of efficacy in the field

To assess the efficacy of the EcoTape treatment for CM control, field trials were conducted over a 4-year period (2004-2007) in an experimental site of Trento Province (Borgo Valsugana). Five 3-ha orchards, planted with 3-5-m-tall apple trees of c.v. Golden Delicious (rootstock M9, spacing of 3.5 x 1.2 m) and currently under conventional farming management, were selected.

The first orchard was treated with EcoTape at the deployment rate of 4,700 dispensers/ha over the 4-year study period.

The second orchard, in 2005 and 2006, was treated with EcoTape with an application rate of 2,350 dispensers/ha.

The third orchard, in 2004 and 2005, was treated with Ecodian CP dispensers (Isagro; 2,000 dispensers/ha, each loaded with 10 mg of E8,E10-12OH), chosen as pheromone reference because it also uses a high density of pheromone point sources.

The fourth orchard, for 2005 to 2007, was conventionally managed with pesticides, receiving two applications of flufenoxuron (720 g/ha), one application of chlorpyriphos-ethyl (840 g/ha), and one application of diazinon (2,400 g/ha), and was considered as the chemical reference.

The fifth orchard served as the untreated control over the 4-year period.

All the pheromone treatments were placed in the field once before the first CM flight. In 2004, 2005, and 2006, flufenoxuron at 720 g/ha was applied in early May and again in late May to control leafrollers in plots managed with pheromone. In 2007, an insecticide (chlorpyriphos-ethyl, 840 g/ha) was applied (3 August) in EcoTape and Ecodian plots to reduce a high CM infestation.

At the end of the first and second CM generation, 6,000 apple fruits per orchard, randomly selected from the inner part of the rows, were examined. Damage caused by CM larvae was expressed as percentage of damaged fruits.

CM population density and disruption of male orientation were estimated by placing monitoring traps (four Pomotraps/orchard, baited with standard rubber lures containing 1.0 mg E8,E10-12:OH, Isagro) in untreated and insecticide-treated orchards or 5.0 mg E8,E10-12:OH in pheromone-treated orchards (Charmillot, 1990). Monitoring lures were replaced every 42 days. The traps were hung in the upper third of the canopy (Knight, 2007) and checked weekly.

Statistical analysis

Release rate data were compared across treatments (dispensers of different field age) using one-way ANOVAs, followed by Tukey's test for post hoc comparisons of mean values.

For each behaviour recorded in the wind tunnel, the percentages of responding males were compared using a χ^2 test after Yates' correction followed by a Ryan's multiple comparison test on proportions (Ryan, 1960) ($P < 0.05$).

The mean number of captured males was $\sqrt{(x + 0.5)}$-transformed and compared among treatments using one-way ANOVA, followed by Tukey's test for post-hoc comparison of mean values.

The yearly percentage of damaged fruits at the end of first and second moth flight was compared among treatments using a χ^2 test after Yates' correction followed by a Ryan's multiple comparison test on proportions ($P < 0.05$). Over the 4-year study period the mean percentage of damaged fruits was compared among treatments by means of non parametric ANOVA (Kruskal-Wallis test) followed by a Ryan's multiple comparison test on proportions ($P < 0.05$).

The software package used was Statistica 7.1.

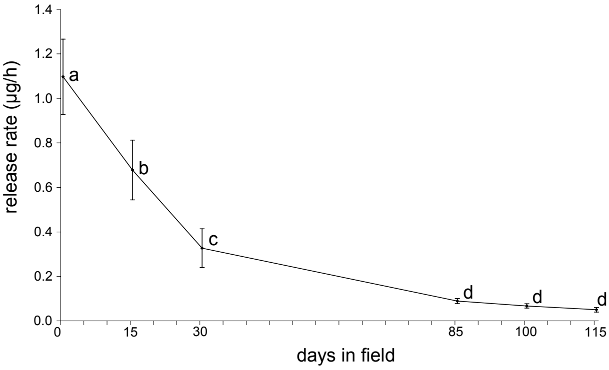

Figure 1. E8,E10-12:OH release rate (mean ± SD) of EcoTape dispensers (n = 10) measured by SPME after different periods of field ageing. EcoTape dispensers were placed in an apple orchard at Borgo Valsugana (Trento, Italy) on 11 May 2006. Different letters indicate values that are significantly different (ANOVA, Tukey's test: $F = 197.1$; d.f. = 5,54; $P < 0.001$).

Results

Release rate of dispensers

The calculated release rates of E8,E10-12:OH from new and field-aged EcoTape dispensers are shown in figure 1. The emission significantly decreased during the first period, from day 0 to day 30, while it did not differ substantially in the second period, from day 85 to 115, when, however, the emission releases were significantly lower than those corresponding to the first period ($P < 0.001$).

Wind tunnel bioassay

The proportion of virgin males contacting (both touching and landing) on EcoTape dispensers not previously exposed in field (65%) was significantly higher than the proportion contacting on field-aged dispensers or a standard monitoring lure ($P < 0.001$) (table 1). After 15 days of field exposure, 10% of males contacted the EcoTape point source; this value did not change significantly over the rest of the field period. With regard to the percentage of activation, no significant differences were found among the tested dispensers ($P = 0.17$). The oriented upwind flights within 10 cm from the source had decreased significantly if the dispensers had aged in the field for 115 days, i.e., until the end of the season ($P < 0.01$).

Field trapping

Traps baited with aged EcoTape dispensers attracted CM males throughout the flight period (table 2). At the end of each CM flight, the attractiveness of EcoTape dis-

Table 1. Percentage of *C. pomonella* virgin males (n = 20) responding to EcoTape dispensers (aged in the field for 0 to 115 days) in a wind tunnel and to a standard lure (monitoring plastic vial loaded with 1 mg E8,E10-12:OH).

CM flight period	EcoTape dispensers[1] (days in field)	% males responding[2]		
		activation	oriented flight until 10 cm	touching and landing
1st	0	100 a	80 a	65 a
"	15	95 a	65 ab	10 b
"	30	95 a	60 ab	10 b
2nd	85	90 a	50 ab	25 b
"	100	80 a	40 ab	15 b
"	115	75 a	35 b	10 b
	Standard lure (1 mg)[3]	95 a	80 a	15 b
χ^2		9.1	16.0	28.3
d.f.		6	6	6
P		0.17	<0.01	<0.001

[1] EcoTape dispensers were placed in an apple orchard at Borgo Valsugana (Trento, Italy) on 11 May 2006.
[2] Values within the same column followed by the same letter are not statistically different (χ^2, Ryan's multiple comparison test on proportion, P < 0.05).
[3] A standard lure (a monitoring plastic vial loaded with 1 mg of E8,E10-12:OH and not aged in the field) was used for comparison.

Table 2. Number of *C. pomonella* males caught in traps baited with differently aged EcoTape dispensers and with a standard lure (monitoring rubber septum loaded with 1 mg E8,E10-12:OH).

Trap lure[1]	Dispenser replacement[2]	Trap captures[3]		
		1^{st} flight	2^{nd} flight	yearly catches
EcoTape	14 days	18.3 ± 6.1 a	5.3 ± 3.0 a	23.7 ± 3.0 a
EcoTape	30 days	25.0 ± 7.0 a	11.0 ± 6.2 a	36.0 ± 2.0 bc
EcoTape	-	21.0 ± 3.6 a	16.0 ± 3.5 a	37.0 ± 4.3 c
Standard (1 mg)	42 days	13.00 ± 5.6 a	12.3 ± 0.6 a	25.3 ± 6.1 ab
F		2.3	3.8	8.3
d.f.		3,8	3,8	3,8
P		0.150	0.056	0.008

[1] Traps were placed in an untreated apple orchard at Borgo Valsugana (Trento, Italy) on 11 May 2006.
[2] EcoTape dispensers were replaced with one aged on the tree canopy every 14 days, every 30 days or left in the trap all over the season; standard lures were replaced every 42 days.
[3] Values are means ± SD of 3 replicate traps; means within the same column followed by the same letter are not significantly different (ANOVA, Tukey's test, P < 0.05).

pensers and standard monitoring lures was not significantly different, although for the second CM flight the number of captures in traps containing EcoTape dispensers replaced every 14 days was lower than the number in the other traps (1^{st} flight: P = 0.15; 2^{nd} flight: P = 0.056). The mean overall number of males caught per trap was similar to traps containing an EcoTape dispenser that was replaced every 14 days with a dispenser aged in the tree canopy and to traps containing a standard monitoring lure. These values were significantly lower than those recorded in traps containing dispensers replaced every 30 days and in traps containing dispensers that were not replaced over the season and were protected in the trap (P < 0.05).

Evaluation of efficacy in the field

The percentage of injured fruits in EcoTape-treated plots and in the reference areas are shown in table 3. At the end of each CM generation, a significantly lower percentage of injured fruits was recorded in pheromone-treated orchards than in the untreated reference, both in 2004 (P < 0.0001) and 2005 (P < 0.0001) as well as in 2006 (P < 0.0001) and 2007 (P < 0.0001). These values were lower or similar than in the orchard managed with curative insecticides. The percentages of attacked fruits were statistically similar with the two densities of EcoTape dispenser (2,350 and 4,700/ha), even though in 2006 the higher density was more effective. The mean percentage of fruit damage recorded over the 4-year study period in the plots treated with EcoTape and Ecodian was significantly lower than that both in the chemical and in the untreated reference orchard (P < 0.001).

The numbers of CM males captured each year in monitoring traps are reported in table 4. A significantly greater number of males was captured in pheromone monitoring traps located in untreated and insecticide-treated plots than in plots treated with EcoTape and Ecodian dispensers, both in 2004 (P < 0.001) and 2005 (P < 0.001). Similar data were recorded in 2006 (P < 0.001) and 2007 (P < 0.01). The number of captured males was similar in pheromone-treated plots (EcoTape and Ecodian).

Table 3. Field efficacy of EcoTape and other management strategies against *C. pomonella* from 2004-2007 at Borgo Valsugana (Trento, Italy).

Management[3]	Fruit damage (%)[1]								Summarized (%)[2]
	2004		2005		2006		2007		2004-2007
	1st generation	2nd generation	1st generation	2nd generation	1st generation	2nd generation	1st generation	2nd generation	
EcoTape (4,700/ha)	0.01a	0.30a	0.13a	0.48ab	0.10a	0.43a	0.30a	2.65b	0.55 ± 0.31a
EcoTape (2,350/ha)	-	-	0.01a	0.12a	0.15a	1.10ab	-	-	0.34 ± 0.25a
Ecodian	0.03a	0.60a	0.16a	0.16a	-	-	-	-	0.24 ± 0.12a
Conventional	-	-	2.00b	1.40b	1.00b	1.70b	1.20b	1.00a	1.62 ± 0.29b
Untreated	21.40b	10.20b	13.40c	8.30c	21.40c	24.80c	3.20c	10.20c	14.11 ± 2.69c
χ^2	2752.9	1067.0	2650.0	1443.7	3716.1	3893.0	171.4	655.7	22.2
d.f.	2	2	4	4	3	3	2	2	4
P	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.001

[1]Yearly percentage of fruit damage (n = 6,000 fruits) at the end of the first and second CM generation. Values within the same column followed by the same letter are not significantly different (χ^2, Ryan's multiple comparison test on proportion, P < 0.05).

[2]Percentage (means ± SD) of fruit damage over the 4-year study period. Values within the same column followed by the same letter are not significantly different (Kruskal-Wallis, Ryan's multiple comparison test on proportion, P < 0.05).

[3]Orchards were treated with two deployment rates of EcoTape dispensers (4,700 and 2,350 dispensers/ha), while references were treated with Ecodian dispensers (2,000/ha), conventionally managed, or left untreated.

Table 4. Number of *C. pomonella* males captured in monitoring traps (n = 4) placed in plots managed with different strategies during 2004-2007 at Borgo Valsugana (Trento, Italy).

Management[2]	Trap captures per year[1]			
	2004	2005	2006	2007
EcoTape (4,700/ha)	2.0 ± 3.6 a	0.0 ± 0.0 a	0.0 ± 0.0 a	12.3 ± 9.2 a
EcoTape (2,350/ha)	-	0.0 ± 0.0 a	0.2 ± 0.4 a	-
Ecodian	1.3 ± 1.0 a	0.0 ± 0.0 a	-	-
Conventional	-	32.5 ± 14.8 b	46.0 ± 4.2 c	54.7 ± 18.3 b
Untreated	29.7 ± 8.6 b	67.5 ± 13.8 c	22.2 ± 7.9 b	82.3 ± 8.3 b
F	52.3	57.8	98.3	22.8
d.f.	2,13	4,13	3,14	2,6
P	< 0.001	< 0.001	< 0.001	0.002

[1]Traps were baited with standard rubber septa, which contained 1.0 mg E8,E10-12:OH in untreated or insecticide-treated plots and 5.0 mg E8,E10-12:OH in pheromone-treated ones. Values (means ± SD) within the same column followed by the same letter are not significantly different (ANOVA, Tukey's test, P < 0.05).

[2]Plots were treated with two deployment rates of EcoTape dispensers (4,700 and 2,350 dispensers/ha), while reference plots were treated with Ecodian dispensers (2,000/ha), conventionally managed, or left untreated.

Discussion

Field trials showed that EcoTape can efficiently control CM. In the climate of Trento Province (Northern Italy), a single application of EcoTape controlled the pest throughout the entire season, even in small (from 2- to 5-ha) orchards. In all 4 years of this study, the damage caused by CM at harvest was similar in plots managed with EcoTape, conventional insecticides, and Ecodian; the latter can be considered intermediate between EcoTape and conventional MD with respect to the total amount of codlemone and density of pheromone point sources (Angeli *et al.*, 2007). The percentage of fruit damaged in EcoTape-treated plots was always below the economic threshold of 1% (Waldner, 2005), except in 2007 when a high CM infestation required an additional insecticide application. The higher rate of pheromone dispensers, 4,700 instead of 2,350/ha, did not statistically improve the efficacy of EcoTape, as previously reported by Boselli *et al.* (2006) in orchards characterized by different climatic conditions and canopy structure.

During the season, the number of males caught in standard monitoring traps was always less in areas managed with EcoTape and Ecodian pheromone dispensers than in untreated and conventionally treated plots. This reduction in capture demonstrated that the pheromone treatments disrupted CM mating (Charmillot, 1992). Field trapping data showed that the EcoTape formulation remained active until the end of the season: a single dispenser, exposed to field conditions, was able to attract CM males during the entire flight period, and the number of captures was similar with EcoTape and a monitoring lure. Dispensers that were protected in traps for a longer time, however, were slightly more attractive to CM males than those aged in the tree canopy. This suggests that the attractiveness of the formulation could be increased by increasing its protection from field conditions.

Data on pheromone release rate and from behavioural bioassays in a wind tunnel confirmed that EcoTape dispensers release pheromone throughout the season. Before dispensers were placed in the field, the amount of synthetic pheromone emitted by a single dispenser was approximately 180 times higher than that reported for a CM calling female (Bäckman *et al.*, 1997), 3 times lower than that of an Ecodian dispenser (Angeli *et al.*, 2007), and considerably lower (30-120 times) than those of several devices used in conventional CM mating disruption (Brown *et al.*, 1992; Knight, 1995; Tomaszewska *et al.*, 2005). After 15 days of field exposure, the rate was comparable with that reported for a standard monitoring lure (Angeli *et al.*, 2007). By the second CM flight, the pheromone emission had dropped to a low level and continued thereafter to decline slowly. Nevertheless, the EcoTape dispensers were still active at the end of the season, when their estimated release rate was about 7 times higher than that of a CM calling female.

In wind tunnel bioassays, CM virgin males were strongly attracted to the EcoTape dispensers not previously exposed in field, as evidenced by close-range oriented flights and frequent touchings and landings. The flight activity elicited by field-aged dispensers did not differ from that elicited from monitoring lures loaded with 1 mg of E8,E10-12:OH. This result was also confirmed in field trapping experiments where an equal number of males was caught during the season in EcoTape-baited traps and in standard monitoring traps. Behavioural and field trapping data suggest that the emission of each EcoTape dispenser is not likely to induce remarkable neurophysiological modifications (such as habituation, adaptation) in males approaching the codlemone source due to high-dosage pheromone exposure, as frequently reported for other commercial MD dispensers (Charmillot, 1990; Witzgall *et al.*, 1999; Stelinski *et al.*, 2004). After investigating the CM flight activity elicited by Ecodian dispensers, Angeli *et al.* (2007) hypothesized that, because the pheromone emission did not elicit close contacts, non-competitive mechanisms were probably involved when males came close to the Ecodian source. Conversely, release rates and attractiveness data from both wind tunnel and field suggest that competition between natural and synthetic sources has a primary role with EcoTape MD (Epstein *et al.*, 2006; Miller *et al.*, 2006).

Even with substantial CM population pressure in the field, which can reduce competition between natural and synthetic pheromone plumes and thereby limit MD (Cardè *et al.*, 1995; Vickers *et al.*, 1998; Witzgall *et al.*, 2008), we found that the EcoTape treatment yielded a low level of fruit injury. Nevertheless, further investigations will be required to determine the number of point sources needed to control different population levels and to better evaluate the effects of climatic conditions and other environmental factors on EcoTape efficacy. The small amount of pheromone released in the environment with a single application of EcoTape, 5-12 g/ha versus 80-200 g/ha with standard reservoir dispenser formulations, may significantly increase its cost effectiveness. In addition, compared to conventional MD, EcoTape application requires a shorter or comparable length of time when applied by hand (1.0-1.5 h/ha) or with the help of a harvest-wagon (3-4 h/ha) (Degen *et al.*, 2005; Baldessari *et al.*, 2008). In conclusion, EcoTape mating disruption eliminates some of the drawbacks of the standard pheromone-based techniques and can be considered a valuable tool for CM control.

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