Assessment of Commercially Available Pheromone Lures for Monitoring Diamondback Moth (Lepidoptera: Plutellidae) in Canola

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J. Econ. Entomol. 103(3): 654–661 (2010); DOI: 10.1603/EC09339

ABSTRACT Sex pheromone monitoring lures from five different commercial sources were compared for their attractiveness to male diamondback moth, *Plutella xylostella* L. (Lepidoptera: Plutellidae) in canola, *Brassica napus* L., fields in western Canada. Lures that had the highest pheromone release rate, as determined by aeration analyses in the laboratory, were the least attractive in field tests. Lures from all the commercial sources tested released more (Z)-11-hexadecenal than (Z)-11-hexadecenyl acetate and the most attractive lures released a significantly higher aldehyde to acetate ratio than less attractive lures. Traps baited with sex pheromone lures from APTIV Inc. (Portland, OR) and ConTech Enterprises Inc. (Delta, BC, Canada) consistently captured more male diamondback moths than traps baited with lures from the other sources tested. In two different lure longevity field trapping experiments, older lures were more attractive to male diamondback moths than fresh lures. Pheromone release from aged lures was constant at very low release rates. The most attractive commercially available sex pheromone lures tested attracted fewer diamondback moth males than calling virgin female moths suggesting that research on the development of a more attractive synthetic sex pheromone lure is warranted.

KEY WORDS pheromone monitoring, *Plutella xylostella*, Lepidoptera, IPM, canola

The diamondback moth, *Plutella xylostella* L. (Lepidoptera: Plutellidae) is a worldwide pest of cruciferous crops (Talekar and Shelton 1993). In the Canadian Prairies, the diamondback moth is considered a serious pest of canola (*Brassica napus* L. and *Brassica rapa* L.) and infestation occurs primarily by migration of adult moths on wind currents from the southern United States each spring (Philip and Mengersen 1989). If sufficient numbers of moths arrive in canola crops and females lay eggs, the resulting larvae and subsequent generations can cause significant damage to canola as they feed on all plant parts at various stages throughout the growing season (Philip and Mengersen 1989). Under outbreak conditions, insecticide application is necessary to control diamondback moth and prevent large yield loss. This has resulted in large acreages of insecticide-treated canola in western Canada. In 1985, ≈467 860 ha was treated with insecticides to control diamondback moth in Alberta and Saskatchewan at a cost of US$11.9 million (Madder and Stemeroff 1988), and more recent outbreaks requiring control have occurred in the prairie provinces in 1995, 2001, and 2005.

Due to the worldwide distribution and pest status of the diamondback moth (Talekar and Shelton 1993), populations are monitored in brassicaceous cropping systems around the world. Synthetic sex pheromone lures to monitor adult diamondback moth populations are available from many different companies, but the efficacy of these lures is variable (He et al. 2003), and little work has directly compared available lures in one geographic location. Traps baited with three different commercially available diamondback moth sex pheromone lures differentially attracted males in cabbage fields in Texas (He et al. 2003). Sex pheromone-baited traps have been developed to monitor diamondback moth in canola (Chisholm et al. 1983) and commercially available lures (ConTech Enterprises Inc., Delta, BC, Canada) are currently used in the government-funded Prairie Pest Monitoring Network (http://nlwis-snite2.agr.gc.ca/ppmn/loginFormEn.jsp) to detect the arrival of migrant diamondback moths into the Prairie provinces. Pheromone-baited traps are used to predict population densities of diamondback moth larvae in cabbage (Walker et al. 2003) and threshold trap catch is used to time control measures in cabbage (Reddy and Guerrero 2000). Applications such as these for sex pheromone-baited traps in canola would assist in the management of diamondback moth in this region.

The sex pheromone of the diamondback moth was first isolated from female abdominal preparations by Chow et al. (1974). Tamaki et al. (1977) identified (Z)-11-hexadecenal (Z11-16:Ald) and (Z)-11-hexadecenyl acetate (Z11-16:Ac) as pheromone components in the female pheromone gland extract. The addition of (Z)-11-hexadecen-1-ol (Z11-16:OH) fur-

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Table 1. Description of commercial diamondback moth sex pheromone lures used in experiments 1–6

Exp. no.	Commercial source	Lure batch	Rubber septa lure color, size (diam. × length, mm)
1, 6	*PHERO*BANK, Wangeningen, The Netherlands	13 March 2006/3 April 2006	Red, 9 by 19
	ConTech Enterprises Inc. (PheroTech Int.), Delta, BC, Canada	L3-4120/000 DB050429	Red, 9 by 19
	APTIV Inc. (APT Inc.), Portland, OR	061704/1	Red, 9 by 19
	Trécé Inc., West Adair, OK	DBM3139 40140896	Grey, 9 by 19
	ISCA Technologies Inc., Riverside, CA	IT056	Red, 9 by 19
2	*PHERO*BANK	26 Feb. 2007	Red, 9 by 19
	ConTech Enterprises Inc.	L3-4120/000 W07-1373	Red, 9 by 19
	APTIV Inc.	040406/1	Red, 9 by 19
	Trécé Inc.	DBM3139 40140717	Grey, 9 by 19
	ISCA Technologies Inc.	IT056-2454189	Red, 9 by 19
3, 7	ConTech Enterprises Inc.	L34120/000 DB050429	Red, 9 by 19
4	ConTech Enterprises Inc.	L3-4120/000 W08-3567	Red, 9 by 19
	APTIV Inc.	031008/1	Red, 9 by 19
5	ConTech Enterprises Inc.	L3-4120/000 W07-1373	Red, 9 by 19
	APTIV Inc.	040406/1	Red, 9 by 19

ther synergized male response to the first two components (Koshihara and Yamada 1980) and was later shown to be a minor pheromone component (Suckling et al. 2002). Other compounds have been investigated to enhance male moth response (Chisholm et al. 1983) because virgin female-baited traps consistently capture more males than synthetic pheromone traps over wide geographic regions (Zilahi-Balogh et al. 1995, Suckling et al. 2002). Electrophysiological data indicate an unidentified antennally active compound from diamondback moth female gland extracts (Suckling et al. 2002) that might be an important component in this species pheromone communication system. In Canada, a four-component blend containing the three known pheromone components plus one of (Z)-9-tetradecenyl acetate or (Z)-9-tetradecen-1-ol is recommended for monitoring lures (Chisholm et al. 1983). Inconsistencies in trap capture of male diamondback moth in the Prairie Pest Monitoring Network (S. Meers, personal communication) led us to compare the attractiveness of various commercially available pheromone lures to diamondback moth males for their potential adoption in the monitoring system. This study compares the attractiveness of diamondback moth pheromone lures from five commercial sources to diamondback moths in canola. The two most attractive pheromone lures are further tested for efficacy over time and in comparison to calling virgin females. Pheromone release rate and ratio of the two major pheromone components are analyzed from aerations of lures from all five commercial sources.

Materials and Methods

Field Trapping Comparison of Commercially Available Diamondback Moth Sex Pheromone Lures. Two season-long field trapping experiments tested the hypothesis that commercially available diamondback moth pheromone lures would be equally attractive to male diamondback moths on canola in Alberta, Canada. Pheromone lures from five different companies and a hexane solvent control (100 μl) (Table 1) were tested at each of twenty sites throughout the canola growing regions of Alberta, Canada, in 2006 (exp. 1) and 2007 (exp. 2). Plastic Delta traps (ConTech Enterprises Inc.) were positioned 50 m apart on L-shaped metal hangers ≈1.5 m above the ground along a linear transect at the edge of canola fields in early May in both years. At each site, lures were randomly assigned to traps and suspended from the top of each trap by a pin. Moth flight was monitored and sticky trap inserts were replaced weekly until mid-August in both years. Pheromone lures were changed at 3- and 6-wk intervals throughout the flight period in 2006 and 2007, respectively. Male moth counts in pheromone-baited traps in both experiments were normalized with a log $x + 1$ transformation (Shapiro–Wilk) before analysis. The attractiveness of lures from the different companies was compared in each year with a randomized complete block analysis of variance (ANOVA) on season-long moth counts followed by the Tukey's multiple range test for multiple comparisons among individual treatments. Due to lack of moth capture at some sites, data from 12 and 15 sites were used in the analysis for 2006 and 2007, respectively.

Lure Longevity of Commercially Available Diamondback Moth Sex Pheromone Lures. Two field trapping experiments (exps. 3 and 4) tested the hypothesis that male diamondback moth attraction to pheromone lures would vary with lure age. In 2006 (exp. 3), commercially available diamondback moth lures used in the Prairie Pest Monitoring Network (ConTech Enterprises Inc.) were held in groups of 10 in mesh screen bags (10 by 10 cm) and suspended from the top of a Wing trap (ConTech Enterprises Inc.) positioned in a shaded outdoor enclosure on the University of Alberta campus (53° 34′ N, 113° 31′ W). Different groups of lures were aged outdoors in separate traps for 0, 2, 4, 6, and 8 wk before use in the experiment. The average maximum daily temperature during the 8-wk lure aging process (8 May–3 July 2006) was 22.15 ± 5.89°C (mean ± SD). Variously aged lures were transported in refrigerated containers to ten field sites in southern Alberta at the beginning of July 2006 and randomly assigned to plastic Delta traps (ConTech Enterprises Inc.) at each site. Traps were positioned 50 m apart on L-shaped metal hangers ≈1.5 m above the ground along a linear transect at the

edge of canola fields. Male moth counts were monitored weekly for 3 wk and weekly counts were pooled within treatment and log x + 1 transformed before analysis. The attractiveness of differently aged lures was compared with a randomized complete block ANOVA followed by the Tukey's multiple range test for multiple comparisons among differently aged lures. Experiment 4 was conducted in 2008 and tested the attractiveness of differently aged lures (0, 4, and 8 wk old) from two commercial sources (APTIV Inc., Portland, OR and ConTech Enterprises Inc.) found to be the two most attractive commercial lures in exps. 1 and 2. Lures from both companies were aged under field conditions and positioned in traps as described for exp. 3. The average maximum daily temperature during the 8-wk lure aging process (14 May–9 July 2008) was 20.95 ± 4.35°C (mean ± SD). In 2008, traps were separated by 30 m at each of eight field sites in southern Alberta and monitored every 2 wk for a 4-wk period. Moth counts were pooled over the collection periods and data were analyzed with a three-way ANOVA without interactions with site, lure source and lure age specified as factors.

Comparison of the Attractiveness of Commercially Available Diamondback Moth Sex Pheromone Lures to Calling Virgin Females. The attractiveness of the two most effective commercial lures (APTIV Inc. and ConTech Enterprises Inc.) was compared with virgin female diamondback moths in a field cage study (exp. 5) conducted in 2007. Three field cages (1.8 by 1.8 by 1.8 m) (Bioquip, Rancho Dominguez, CA) were assembled at least 50 m apart on the University of Alberta South Campus Farm. In each cage, two plastic Delta traps (ConTech Enterprises Inc.) were positioned in the center of the cage, 1 m above the floor and separated by a potted canola plant (variety. Q2) in full flower (1 m diagonally). Test treatments were assigned randomly to one trap in each cage and consisted of 1) one commercial pheromone lure from ConTech Enterprises Inc.; 2) one commercial pheromone lure from APTIV Inc; and 3) three laboratory-reared virgin female diamondback moths (2–3 d old) held individually in fine mesh bags (4 by 2 cm). The other trap in each cage served as an unbaited control trap. Fifteen-25 laboratory-reared virgin male diamondback moths aged 0–10 d posteclosion were placed in each cage and the proportion of released males that was captured in the traps was monitored for three nights. The number of male moths was evenly distributed among cages by age. The experiment was replicated six times with independent groups of moths distributed in equal numbers among cages and fresh pheromone lures and traps used in each replicate. The proportions of released males that were captured in the baited traps in each cage were compared with a randomized complete block ANOVA followed by a Tukey's multiple range test to compare individual treatments.

Release Rate Analysis of Commercial Pheromone Lures Used in Field Experiments. Fresh lures from the five commercial sources compared in Exp. one conducted in 2006 (Table 1) were analyzed to determine the rate and ratio of release of pheromone components in exp. 6. Five lures from the same lots of each commercial source used in exp. 1 (Table 1) were aerated individually under ambient conditions (22–27°C), and volatile emissions were captured once per day for 3 d on Porapak-Q (Supelco, Sigma-Aldrich Canada Ltd., Oakville, ON, Canada) absorbent material using a flow rate of 1 ml/min and extracted in pentane (Caledon Laboratories Inc., Georgetown, ON, Canada). Extracts were analyzed using gas chromatograph-mass spectrometry by using a Saturn Ion trap (Varian, Inc., Palo Alto, CA) fitted with a DB-5 column (50 m by 0.25 i.d.), and the amount of Z11-16:Ald and Z11-16:Ac released from each lure (ng/24 h) was quantified. The total amount of Z11-16:Ald released from each lure from each commercial source over the 72-h aeration period was log transformed and compared by source using a one-way ANOVA followed by a Tukey's multiple range test to compare individual treatments. The total proportion of Z11-16:Ald released from each lure from each commercial source over the 72-h aeration period was compared by source using a Kruskal–Wallis one-way ANOVA on ranks due to unequal variances. A significant effect of commercial lure source was followed by a Tukey's multiple range test to compare individual lure sources.

Lures (ConTech Enterprises Inc.) used in the first lure longevity experiment conducted in 2006 (exp. 3) were saved after the completion of the field experiment and analyzed to determine the rate and ratio of release of pheromone components under laboratory conditions (exp. 7). Five lures from each of the aging treatments (0, 2, 4, 6, and 8 wk) were aerated individually under ambient conditions (22–23°C) and volatile emissions were captured and analyzed as in exp. 6. Because lures were aerated after the completion of the 3-wk field experiment, actual field age of each treatment at the time of analysis was 3, 5, 7, 9, and 11 wk. Only the amount of Z11-16:Ald could be measured reliably. The total amount of Z11-16:Ald released from each lure from each aging treatment over the 72-h aeration period was compared by age group using a randomized block ANOVA.

Statistical Analyses. All analyses were conducted using SigmaStat version 11.0 (Systat Software, Inc. 2008), with α specified as 0.05.

Results

Field Trapping Comparison of Commercially Available Diamondback Moth Sex Pheromone Lures. Diamondback moth population densities in Alberta during the first year of this study (2006) were low and variable (Fig. 1A). In exp. 1, traps baited with APTIV lures captured numerically the most male diamondback moths, but the number of males captured was not significantly different than that captured in traps baited with the ConTech or Trécé Inc. (West Adair, OK) lures (Fig. 1A). Intermediate numbers of male moths were captured in traps baited with ConTech and Trécé lures but capture in traps baited with *PHERO*BANK (Wangeningen, The Netherlands) or

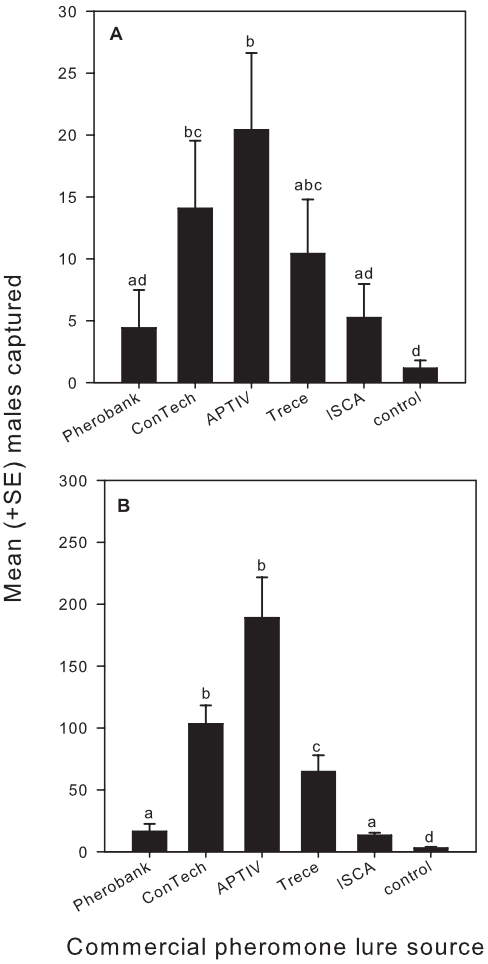

Fig. 1. Mean +SE number of male diamondback moths captured in traps baited with various commercially available sex pheromone lures as compared with solvent control trap in season-long experiments conducted in 2006 (A) and 2007 (B). Lures were replaced at 3-wk intervals in 2006 ($N = 12$ sites) and 6-wk intervals in 2007 ($N = 15$ sites). Within each year, bars marked with the same letter are not significantly different ($P > 0.05$; Tukey's multiple range test).

ISCA Technologies Inc. (Riverside, CA) lures was not significantly different from capture in traps baited with blank control lures (Fig. 1A). In 2007, diamondback moth densities were moderate and this was reflected in higher moth trap capture in all pheromone-baited traps in exp. 2 (Fig. 1B) compared with exp. 1 (Fig. 1A). Season-long trap capture in traps baited with lures from all the commercial sources was significantly higher than capture in traps baited with control lures (Fig. 1B). In exp. 2, traps baited with APTIV and ConTech lures, that are currently used in the Prairie Pest Monitoring Network, captured significantly more male moths than any other lure type (Fig. 1B). As in exp. 1 (Fig. 1A), *PHERO*BANK and ISCA lures attracted the fewest moths of the lures tested in exp. 2 (Fig. 1B).

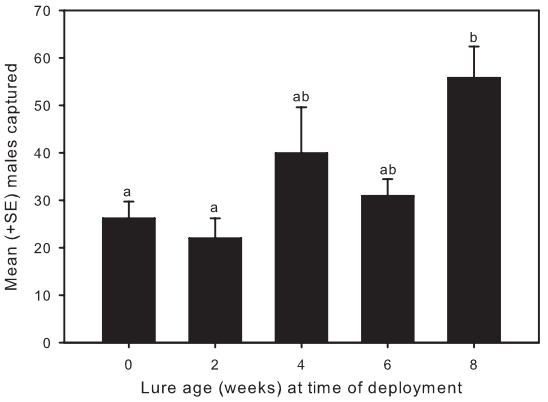

Fig. 2. Mean + SE number of male diamondback moths captured in traps baited with ConTech Enterprises Inc. lures that had been aged outside for various times before deployment in the experiment. Traps baited with the variously aged lures remained in the field for 3 wk at peak flight in 2006 ($N = 10$ sites). Bars marked with the same letter are not significantly different ($P > 0.05$; Tukey's multiple range test).

Lure Longevity of Commercially Available Diamondback Moth Sex Pheromone Lures. There was a significant effect of lure age ($F_{4,36} = 5.3$; $P = 0.002$) on the number of male moths captured in traps baited with ConTech lures in exp. 3 (Fig. 2). Interestingly, traps baited with older lures that had been held outside for 8 wk before deployment in the experiment, were more attractive to males than traps baited with fresh lures or those that had been held outside for 2 wk (Fig. 2). Lure age also significantly affected male moth capture in traps baited with ConTech lures and APTIV lures in exp. 4 ($F_{2,14} = 4.9$; $P = 0.024$) (Fig. 3). Although the effect of lure age was stronger in exp. 3

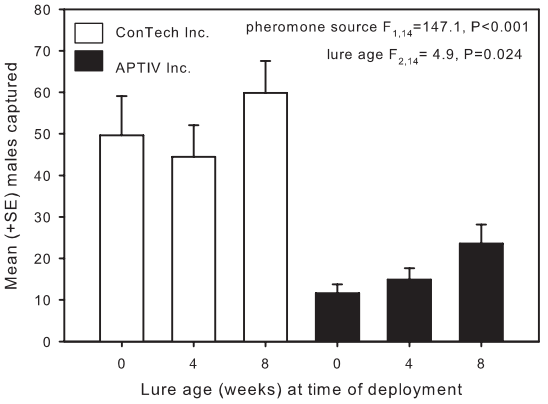

Fig. 3. Mean + SE number of male diamondback moths captured in traps baited with lures from ConTech Enterprises Inc. or APTIV Inc. that had been aged outside for various times before deployment in the experiment. Traps baited with variously aged lures remained in the field for four wks at peak flight in 2008 ($N = 8$ sites). Commercial pheromone source and lure age significantly affected (three-way ANOVA) the number of male diamondback moths attracted to the variously baited traps.

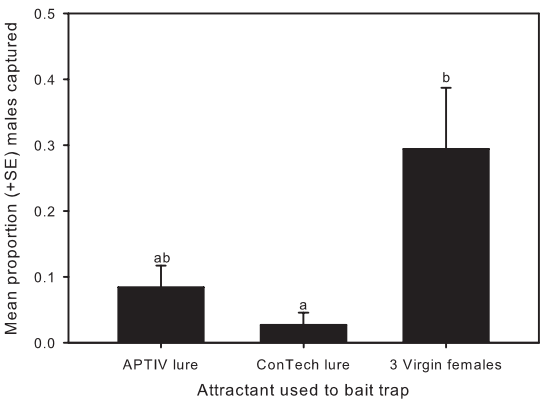

Fig. 4. Mean + SE proportion of released male diamondback moths captured in traps baited with lures from ConTech Enterprises Inc., APTIV Inc., or three virgin diamondback moth females in the field cage experiment conducted in 2007 ($N = 6$). Bars marked with the same letter are not significantly different ($P > 0.05$; Tukey's multiple range test).

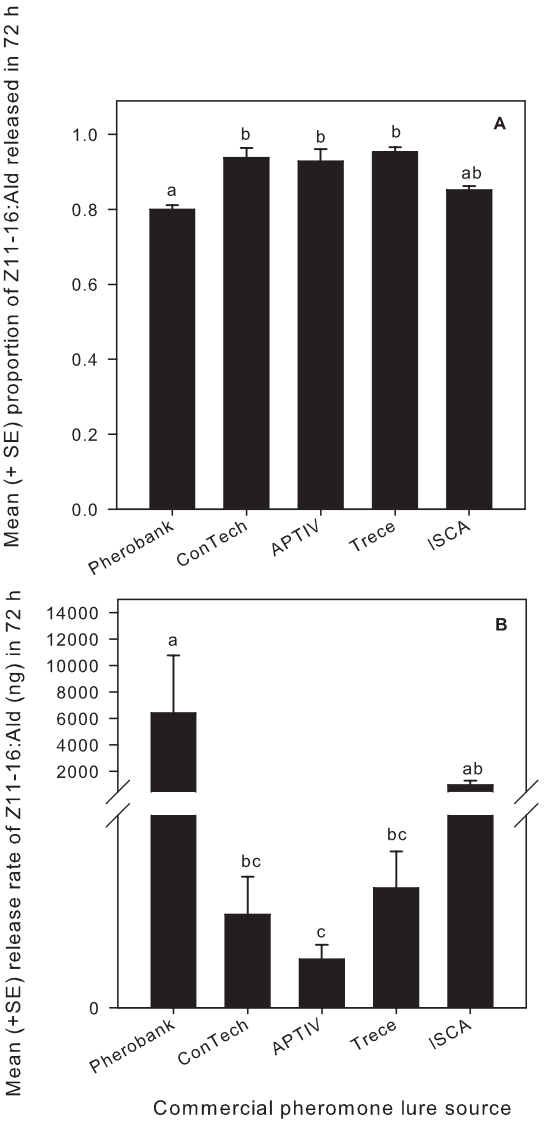

Fig. 5. Mean + SE proportion (A) and release rate (B; nanograms) of Z11-16:Ald released from commercially available lures in 72 h. Lures were aerated individually ($N = 5$). Bars marked with the same letter are not significantly different ($P > 0.05$; Tukey's multiple range test).

than in exp. 4, consistent with exp. 3, older lures in exp. 4 attracted the most male diamondback moths regardless of lure source (Fig. 3). Slightly warmer temperatures during the lure aging period in 2006 (avg. maximum daily temperature, 22.15°C) than in 2008 (average maximum daily temperature, 20.95°C) may have resulted in a higher pheromone release rate before lure placement in the field in 2006 and contributed to the stronger effect of lure aging observed in exp. 3. Contrary to what we found in exps. 1 and 2, traps baited with the ConTech lures captured significantly more ($F_{1,14} = 147.1$; $P < 0.001$) male diamondback moths than traps baited with the APTIV lures in exp. 4 (Fig. 3).

Comparison of the Attractiveness of Commercially Available Diamondback Moth Sex Pheromone Lures to Calling Virgin Females. In the field cage study, there was a significant effect of pheromone source ($F_{2,10} = 5.8$; $P = 0.022$) on the proportion of released male moths captured. Traps baited with three virgin females captured a significantly higher proportion of released males than traps baited with lures from ConTech (Fig. 4). Traps baited with lures from APTIV captured an intermediate proportion of males that was not significantly different from the proportion of males captured in traps baited with ConTech lures or three virgin female moths (Fig. 4). No male diamondback moths were captured in unbaited control traps positioned in field cages.

Release Rate Analysis of Commercial Pheromone Lures Used in Field Experiments. Aeration studies of fresh lures from the five different commercial sources tested in the field in Exp. one indicated that in all cases the major compound released from lures was Z11-16:Ald (Fig. 5A). Z11-16:Ac was released as a minor component and Z11-16:OH was not detected. The proportion of Z11-16:Ald: Z11-16:Ac released varied significantly among the different sources of commercial lures ($H_4 = 16.8$, $P = 0.002$) and was highest in lures from ConTech, APTIV, and Trécé (Fig. 5A), which were the lures that attracted the most male diamondback moths in exps. 1 and 2 (Fig. 1). *PHERO*BANK lures released the lowest and ISCA lures released an intermediate proportion of Z11-16:Ald: Z11-16:Ac (Fig. 5A). Pheromone release rate from the lures differed widely among lures from the different commercial sources ($F_{4,20} = 10.6$; $P < 0.001$) (Fig. 5B). *PHERO*BANK and ISCA lures released the most pheromone and ConTech and Trécé lures released an intermediate amount and APTIV released the least pheromone (Fig. 5B). Interestingly, lures that released the most pheromone were the least at-

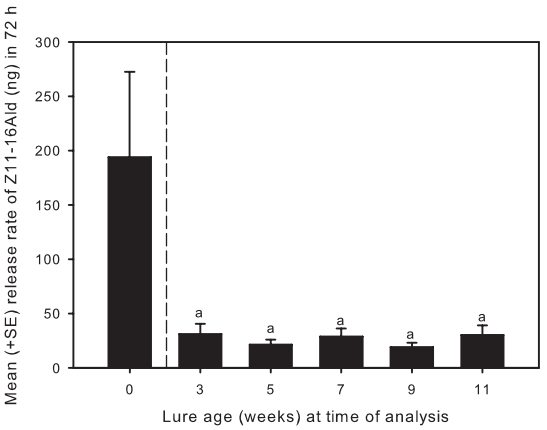

Fig. 6. Mean + SE release rate (nanograms) of Z11-16:Ald released from lures from ConTech Enterprises Inc. after various periods of time in the field. Lures were aerated individually ($N = 5$). Bars marked with the same letter are not significantly different ($P > 0.05$; Tukey's multiple range test). Release rates of aged ConTech Enterprises Inc. lures (exp. 7) are visually compared with the release rate from fresh ConTech Enterprises Inc. lures (exp. 6) from a different lure batch.

tractive to male diamondback moths in field studies (Fig. 1). Release rate of the major aldehyde component (Fig. 6) was low and steady after ConTech lures were field aged for 3–11 wk in exp. 7. There was no significant difference in the amount of Z11-16:Ald released from lures aged 3–11 wk ($F_{4,16} = 0.9$; $P = 0.487$) (Fig. 6). When the release rate of fresh ConTech lures measured in the first aeration study (exp. 6) is visually compared with the aged lures in this study (exp. 7), it seems that there is an initial burst of pheromone release that is diminished by three wks of release under field conditions (Fig. 6).

Discussion

In our study conducted over two field seasons, male moths were consistently captured in greater numbers in traps baited with lures from APTIV Inc., ConTech Enterprises Inc., and Trécé Inc. compared with traps baited with lures from *PHERO*BANK, and ISCA Technologies Inc. Based on aeration analyses of pheromone emitted from commercial lures in the same lot as those tested in the field, lures that release less pheromone are more attractive in the field. Arrestment of pheromone-mediated behaviors to high release rates of pheromone occurs in other moth species (Baker et al. 1981) and has been reported for diamondback moth (Kawasaki 1984, Lin et al. 1982, Môttus et al. 1997). Pheromone release rates of 8–17 ng/h resulted in maximum trap catches of diamondback moths in cabbage fields in Estonia (Môttus et al. 1997). Lures releasing between 2 and 8 ng/h Z11-16:Ald and Z11-16:Ac and 13–152 ng/h Z11-16:OH attracted male diamondback moths in traps positioned in cabbage fields in Florida (Mayer and Mitchell 1999). Our results indicate that average pheromone (Z11-16:Ald) release rates of <5 ng/h measured from the most attractive commercial lures attract more male diamondback moths than lures with higher average release rates of 13.5 ng/h (ISCA Technologies Inc.) and 89.2 ng/h (*PHERO*BANK).

Our results also indicate that the ratio of pheromone components released from commercially available pheromone lures may influence their attractiveness to male diamondback moths. Although the major pheromone component released from all the commercial lures tested was Z11-16:Ald, the most attractive lures had a higher proportion of Z11-16:Ald to Z11-16:Ac than less attractive lures. Male diamondback moths are attracted to a broad range of pheromone blends with different ratios of the three identified pheromone components (Mayer and Mitchell 1999), and there is the possibility of geographic variation in male response to (Zilahi-Balogh et al. 1995) and production of pheromone (Suckling et al. 2002, He et al. 2003, Yang et al. 2007). In Korea (Yang et al. 2007) and New Zealand (Suckling et al. 2002), females produce and males maximally respond to pheromone blends with Z11-16:Ac as the main component. In contrast, females in North America produce a 3:1:2 ratio of Z11-16:Ald: Z11-16:Ac:Z11-16:OH (He et al. 2003), and males respond maximally to rubber septa lures loaded with a 7:3:0.1 ratio of these same components (Chisholm et al. 1983). Both blend and release rate of pheromone emitted from lures differed in this study; therefore, it is difficult to determine which factor is driving the differential attractiveness of lures in field tests.

The importance of low pheromone release rate for attraction of male diamondback moths is also supported by our findings in the two lure longevity experiments in which older lures attracted more males. The release rate of Z11-16:Ald from lures used in the first lure longevity experiment did not differ significantly among lures aged under field conditions for 3–11 wk; however, release rates of aged lures were substantially lower than that from fresh ConTech Enterprises Inc. lures measured in exp. 1. The release rate of Z11-16:Ald from rubber septa follows a first-order process (Môttus et al. 1997, Mayer and Mitchell 1999), and its half-life is 231 d on rubber at 20°C (McDonough, 1991) or 46 d on rubber disk segments held under field conditions in Estonia (Môttus et al. 1997). Lures tested in our assays were field-aged between 21 and 77 d and displayed little variation in release rate which averaged <0.5 ng/h. Because release rate of Z11-16:Ald did not differ in aged lures, increased attractiveness of older lures might be due to differential release rates of the pheromone components with lure age. The released ratio of Z11-16:Ald and Z11-16:Ac from the same lure differs with lure age due to the longer half-life of Z11-16:Ac (Môttus et al. 1997). We were unable to reliably measure Z11-16:Ac released from aged lures in our experiment. Diamondback moth trap catch was similar in traps baited with fresh rubber disk lures and those that had been field-aged for 45 d before deployment in the field for a 20-d bioassay in Estonia (Môttus et al. 1997). Two-week old rubber septa lures captured fewer diamondback moth

males than fresh lures positioned in cabbage fields in Florida (Mayer and Mitchell 1999), and trap catch decreased with lure age from 0 to 70 d in cabbage fields at two locations in India (Reddy and Urs 1996). Increased moth catch in traps baited with older lures in our study is economically important because it suggests that lure-change intervals can be extended throughout the canola growing season in western Canada. In comparison with other studies (Môttus et al. 1997, Mayer and Mitchell 1999), our findings also emphasize the strong influence of environmental factors on emission rates from septa that are likely to vary drastically with geographic location (Mayer and Mitchell 1999).

Although commercially available pheromone lures from ConTech Enterprises Inc. and APTIV Inc. were consistently the most attractive commercially available lures tested in field assays, three calling virgin female diamondback moths in field cage experiments attracted a greater proportion of released males than ConTech lures. Traps baited with APTIV lures captured an intermediate proportion of released males that did not differ from either the ConTech lure- or female-baited traps. Pheromone release from virgin female diamondback moths is restricted between the second and eighth hour of an 8-h scotophase (Pivnick et al. 1990). The constant release of pheromone from synthetic lures has the potential to attract males outside the female calling period and elevate the overall number of male moths captured in synthetic pheromone compared with female-baited traps. Other studies that have compared the attractiveness of synthetic lures to calling diamondback moth females have been conducted in the field where active space of the pheromone plume can affect the number of males drawn into a pheromone trap (Zilahi-Balogh et al. 1995, Reddy and Urs 1996, Suckling et al. 2002). Despite differences in experimental approach based on assay design and composition of the diamondback moth pheromone lure, virgin females out competed synthetic lures in experiments conducted in Indonesia (Zilahi-Balogh et al. 1995) and New Zealand (Suckling et al. 2002) but not India (Reddy and Urs 1996). This may be because calling females release less pheromone than synthetic lures and are therefore more attractive. Alternatively, there may be unidentified minor pheromone component(s) released by females that are not represented in synthetic pheromone blends. Suckling et al. (2002) discovered an additional antennally active compound in diamondback moth female gland extracts that remains to be identified. This compound may impart greater attractiveness to the pheromone blend released by females (Suckling et al. 2002).

Here, we evaluated five commercially available pheromone lures for their attractiveness in monitoring traps to male diamondback moth infesting canola in western Canada. Lures to monitor male diamondback moth activity in canola fields should be highly attractive due to the patchy distribution of moths that are blown into the Canadian Prairies from the south (Hopkinson and Soroka 2010). Further research is required to develop a synthetic lure that is competitive with natural pheromone sources. Currently, pheromone-baited traps in the Prairie Pest Monitoring Network are used to detect and survey (Hopkinson and Soroka 2010) the arrival of migrating moths. Recent research shows that male moth trap capture in pheromone-baited traps in the Prairie Pest Monitoring Network is correlated with immature stages of diamondback moth sampled in the same fields at moderate but not low population densities (C. Miluch, personal communication). There exists the potential to develop commercially available pheromone-baited traps to serve as tools that can predict the ephemeral nature of diamondback moth population densities in the prairies and inform producers of key thresholds and timing for control efforts.

Acknowledgments

We thank S. Meers (Alberta Agriculture, Food and Rural Development) and L. Dosdall (Department of Agriculture, Food and Nutritional Sciences, University of Alberta) for assistance with site location and collection of trap catch data. Season-long trapping studies were monitored by collaborators located throughout the canola-growing region of Alberta, Canada. Collaborators included canola producers, crop research associations, pest management consultants, crop extension specialists, and researchers. Laboratory-reared diamondback moths used in the field cage study were provided by B. A. Keddie (Department of Biological Sciences, University of Alberta). A. Abdukakharov, R. Adams, E. Chan, M. Ferguson, A. Laycock, and C. Miluch assisted us with insect rearing and fieldwork. This work was supported by the Canola Council of Canada, Canola Agronomic Research Program.

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Received 9 October 2009; accepted 11 March 2010.