Effect of Aging on Pheromone Emission from a Commercial Beet Armyworm (Lepidoptera: Noctuidae) Lure and Trap Efficiency

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ABSTRACT The effect of aging on a commercial pheromone-based lure for attractiveness to male adult beet armyworms, *Spodoptera exigua* (Hübner), was assessed in terms of trapping efficiency and volatile emissions of two key components: (*Z,E*)-9,12-tetradecadienyl acetate and (*Z*)-9-tetradecen-1-ol. In field assays conducted in the Lower Rio Grande Valley, Texas, for 9 wk (June–August 2000) and for 8 wk (March–May) in Tamaulipas, Mexico, 0–1-wk-old lures collected greater than four-fold more male beet armyworm adults than lures that had been aged for 3–4 wk. Using solid phase microextraction and gas chromatographic analysis of the volatiles, mean (*Z,E*)-9,12-tetradecadienyl acetate emission declined by 32% after 5 wk of aging in a ventilated environmental chamber at 29.4°C, 35% RH, to simulate subtropical summers. Mean (*Z*)-9-tetradecen-1-ol emission was reduced by 62% after 4 wk of aging. Under the tropical and subtropical conditions of this study, the capacity of the lure to attract moths into the trap declined after aging for 3 wk. The blend ratio (*Z,E*)-9,12-tetradecadienyl acetate:(*Z*)-9-tetradecen-1-ol declined 29% when the lure was aged for 5 wk. This study will assist in the development of a standard trapping system for assessing adult beet armyworm populations in the tropical and subtropical conditions to which the species is endemic.

KEY WORDS beet armyworm, *Spodoptera exigua*, pheromone, aging

THE BEET ARMYWORM, *Spodoptera exigua* (Hübner), originally from tropical southern Asia and an important pest of many temperate, subtropical, and tropical plants worldwide (Wilson 1932, Metcalf and Luckman 1975, Smits et al. 1987), can build to outbreak status in cotton and other crops (Summy et al. 1996), especially when pesticide applications disrupt beneficial arthropod populations (Eveleens et al. 1973, Raulston et al. 1997). Pheromone-based lures that attract male beet armyworms into traps receive wide use, and the efficiencies of different lure brands, dispensers, trap designs, placements, and colors have been compared (Tingle and Mitchell 1975, Trumble and Baker 1984, Tumlinson et al. 1990, Hendricks et al. 1995, López 1998b).

A variety of factors affect the attractiveness of pheromone-based lures, including dose, release rate, blend of active volatiles, and dispensers (Hardee et al. 1974; Pivnick et al. 1988; Jansson et al. 1990, 1992, 1993; Evenden et al. 1995). Temperature can influence release rates of various pheromone lures to different extents. For example, grandlure (Tumlinson et al. 1969, Dickerson 1986) release rates were found to increase by as much as 13-fold as the temperature was raised from 28 to 62°C (Leonhardt et al. 1988), and for gypsy moth, *Lymantria dispar* (L.), (+)-disparlure release rates from plastic laminate dispensers increased 2.5-fold for every increase of 10°C (Leonhardt et al. 1990). Leonhardt et al. (1988) reported "accelerated aging" of grandlure by increasing temperature, and this resulted in reduced emissions from the "temperature-aged" lure. Kehat et al. (1993) found that the effects on aging on codling moth, *Cydia pomonella* (L.), pheromone dispensers were greater during the summer than during the spring, which was possibly related to temperature.

Effects of aging on pheromone-based lures can vary. For example, after 1 wk of aging pheromone-containing rubber septa, responses of different nitidulid beetle species ranged from 18% of its original value to 90% (Bartelt et al. 1994). Although some researchers report an age-associated decline in the attraction of pheromone-based lures (Leonhardt et al. 1990, López 1998a). Other studies did not detect effects of aging on the attractiveness of pheromone-based lures (Schmidt and Roland 2003).

In the mid-1990s, the boll weevil, *Anthonomus grandis grandis* Boheman, eradication program (Dickerson et al. 2001) in the subtropical Lower Rio Grande Valley, Texas, was associated with a large beet armyworm infestation that has delayed the program there until 2005. If boll weevil eradication is adopted in the tropics and subtropics, it is possible that the beet army-

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worm, already an important pest of cotton in tropical Mexico and other countries within the boll weevil distribution from the United States to Argentina (Ramalho and Jesus 1987, Cuadrado 2002), might require a strong monitoring system that relies on trapping with pheromone-based lures.

The longevity of the Trécé (Salinas, CA) lure's efficiency at attracting adult male beet armyworms was reported to be 23 d under the temperate conditions of central Texas (López 1998a), but the same lure also was reported to be efficacious for 4–6 wk (Trécé 1997). The purpose of this study was to determine the effect of age on the capacity of a pheromone-based lure to attract male beet armyworm adults under tropical or subtropical field conditions and on emission of the pheromone's key volatile components.

Materials and Methods

Trapping Efficiency. Trécé beet armyworm lures, in the form of impregnated rubber septa, were purchased from Great Lakes Integrated Pest Management (Vestaburg, MI). The experiment was conducted between 23 June and 18 August 2000, when beet armyworm populations were high, 8 km south of San Benito, Cameron County, Texas. The five treatments were comprised of control septa without pheromone, nonaged septa, and septa with pheromone aged inside separate Unitraps (International Pheromone Systems Ltd., Ellesmere Point, England) under field conditions for 1, 2, and 3 wk. Five trap positions 60 m apart were established at each of three locations, or replications, on the edges of commercial cotton fields that were located >1 km apart. The position of each treatment was randomized weekly within every replicate to reduce the possibility of positional effects. Each treatment was allowed to collect moths for a week. When a lure had aged 4 wk, it was taken to the laboratory and discarded. The same experiment was conducted 5 km south of Gonzales, Tamaulipas, Mexico, for 8 wk, 23 March and 24 May 2000.

At each trap position, a metal rod was driven vertically into the ground such that the top was 1.2 m above soil level. A 30-cm-long horizontal rod was welded at one end to the top of the vertical rod and a Unitrap was suspended 1 m above the ground from the free end of the horizontal rod. A Hercon Vaportape (Hercon Environmental, Emigsville, PA) strip was placed inside each trap to reduce escapes. The traps were emptied at the end of each week when treatment positions were changed, the Vaportape was replaced with fresh Vaportape, and the numbers of beet armyworm adults were counted.

Lure Emissions. Treatments were Trécé lures aged in ventilated environmental chambers for 1, 2, 3, 4, 5, or 6 wk at 29.4°C, a photoperiod of 12:12 (L:D) h, and 32% RH, conditions that approximate summer field conditions in the Lower Rio Grande Valley; nonaged lures and rubber septa without the lure (aged in the environmental chambers) were used as a control (n = 10). Each septum was suspended from a wire inside a 20-ml vial. The air inside each vial was mixed with any volatiles emanating from the septum by using a magnetic stir bar. Volatiles were sampled using solid phase microextraction (SPME) (Bartelt 1997) with a polydimethylsiloxane-coated (100-μm coating) fiber (Supelco, Bellefonte, PA). The fiber was inserted into the vial through a hole in the vial cap with the same diameter as the fiber to prevent leakage. Sampling time was 1 h at 30°C.

Volatilized (*Z,E*)-9,12-tetradecadienyl acetate and (*Z*)-9-tetradecen-1-ol, components of the attractant pheromone, were quantified using a Shimadzu gas chromatograph-17A (Shimadzu Scientific Instruments, Columbia, MD) with a flame ionization detector. Injection of volatiles was accomplished by thermal desorption from the SPME fiber at 230°C with a splitless injector. The split valve opened 0.5 min after injection. The Hewlett–Packard (Palo Alto, CA) HP-1 cross-linked methyl siloxane capillary column, 30 m in length by 0.32 mm in diameter with 0.25-μm film thickness and a 320 phase ratio, was used to isolate lure components at 200°C for 10 min, followed by an increase 240°C (10°C/min). The carrier gas was helium at a linear velocity of 50 cm/s. Chromatographic peak areas were integrated using Millenium 2010 chromatography manager (Waters, Milford, MA) software.

Weekly beet armyworm trap captures from both experiments were analyzed as a randomized block design using repeated measures analysis of variance (ANOVA) (Analytical Software 1998). Differences in SPME peak areas were detected by one-way ANOVA, and means were separated using Tukey's honestly significant difference (HSD) test (Analytical Software 1998). Ratios between (*Z,E*)-9,12-tetradecadienyl acetate and (*Z*)-9-tetradecen-1-ol emissions were calculated, and ratios were arcsine square-root transformed before one-way ANOVA and Tukey's HSD test (Analytical Software 1998).

Results

Trapping Efficiency. Repeated measures analysis of trapped male beet armyworms in Texas detected a treatment effect (F = 26.17; df = 4, 88; $P < 0.0001$). When male moth activity was greatest during weeks 2–7, the 0–1-wk-old lure was the most efficient, followed by the 1–2-, 2–3-, and 3–4-wk-old lures in that order, and the control collected the fewest (Fig. 1A). In Tamaulipas, male moth activity was greatest during weeks 1–5 when treatment effects were found, and the same trends observed in Texas were found (F = 21.44; df = 4, 98; $P < 0.0001$) (Fig. 1B). In both Texas and Tamaulipas, treatment efficiencies were not significantly different ($P > 0.05$) when trap catches were uniformly low, such as on weeks 1, 8, and 9 in Texas and on weeks 6–8 in Tamaulipas (Fig. 1A and B).

Lure Emissions. Nonaged lures, and lures aged 1–3 wk had more (*Z,E*)-9,12-tetradecadienyl acetate than lures aged 5–6 wk and control lures with no pheromone (F = 25.08; df = 7, 79; $P < 0.0001$) (Fig. 2). Although differences between treatments were not always detected, (*Z,E*)-9,12-tetradecadienyl acetate emissions declined <13% between consecutive weeks

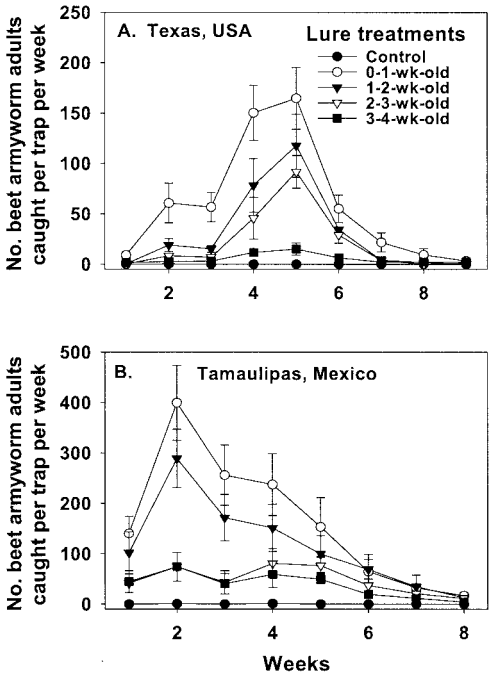

Fig. 1. Mean numbers (±SE) of adult male beet armyworms collected weekly in traps with sex pheromone-based lures that were aged 0–1, 1–2, 2–3, and 3–4 wk before use, and a control without pheromone over nine consecutive weeks (23 June–18 August 2000, Cameron County, Texas (A), and over eight consecutive weeks (5 April–24 May 2000, Tamaulipas, Mexico; $n = 3$) (B).

from weeks 0 to 4. By the fifth and sixth weeks, emissions dropped 32 and 49%, respectively, from the mean level at the end of 4 wk ($P < 0.05$) (Fig. 2). Nonaged lures and 1-wk-old lures had significantly more (Z)-9-tetradecen-1-ol than lures aged 4–6 wk, and the control ($F = 25.78$; df = 7, 79; $P < 0.0001$). Lures aged

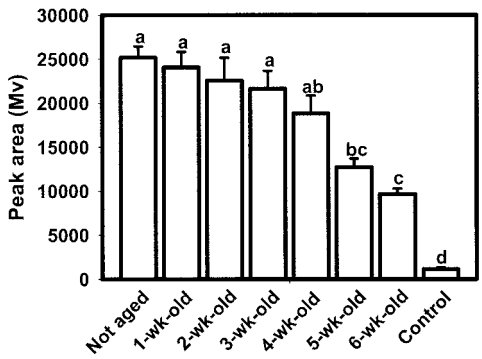

Fig. 2. Mean (±SE) peak areas (recorded as millivolts) of (Z,E)-9,12-tetradecadienyl acetate volatile emissions from beet armyworm sex pheromone-based lures aged 0–6 wk, and a control without pheromone, as determined using solid phase microextraction for gas chromatographic analysis, $n = 10$. Bars with different letters are different ($P < 0.05$), Tukey's HSD test.

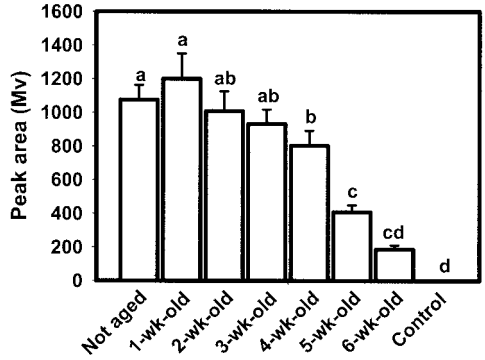

Fig. 3. Mean (±SE) peak areas (recorded as millivolts) of (Z)-9-tetradecen-1-ol volatile emissions from beet armyworm sex pheromone-based lures aged 0–6 wk, and a control without pheromone, as determined using solid phase microextraction for gas chromatographic analysis, $n = 10$. Bars with different letters are different ($P < 0.05$), Tukey's HSD test.

4, 5, and 6 wk had 22, 62, and 83% less (Z)-9-tetradecen-1-ol, respectively, than the nonaged lure (Fig. 3).

The ratios of (Z,E)-9,12-tetradecadienyl acetate: (Z)-9-tetradecen-1-ol volatile emissions were greater than or equal to the nonaged control during the first 4 wk of aging. At ages 5 and 6 wk, the blend ratio declined 29 and 55%, respectively, compared with the control ($F = 13.41$; df = 6, 69; $P < 0.0001$) (Fig. 4).

Discussion

Both field assays showed that in tropical and subtropical conditions, fewer beet armyworm adults were captured in traps with 3–4-wk-old lures than 0–1-wk-old lures, and this agrees with the findings from temperate areas (López 1998a). Emissions of (Z)-9-tetradecen-1-ol were lower in lures aged >3 wk compared with 0–1-, 1–2-, and 2–3-wk-old lures. The moth trapping and volatile emissions results together suggest that (Z)-9-tetradecen-1-ol was the ingredient that influenced trap captures to the greatest extent. Leonhardt et al. (1990) found that laminate lures for

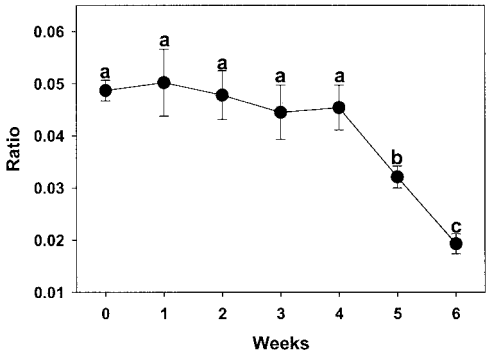

Fig. 4. Mean ratios (±SE) of (Z,E)-9,12-tetradecadienyl acetate:(Z)-9-tetradecen-1-ol volatile emissions from beet armyworm pheromone-based lures aged 0–6 wk.

gypsy moths collected large numbers of males when the release rate was at least 30 ng/h, and the residual content was at least 100 μg. The results of our study suggest that, under tropical and subtropical conditions, a dosage threshold might exist after 3 wk.

Boll weevil; sweetpotato weevil, *Cylas formicarius* (Summers); hemlock looper, *Lambdina fiscellaria lugubrose* (Hulst); and bruce spanworm, *Operophthora bruceata* (Hulst) attractions to sex pheromone traps are affected by changes in the blend ratios of the key volatile components (Tumlinson et al. 1969; Jansson et al. 1990, 1992; Evenden et al. 1995). Our study shows that the blend ratio of the two pheromone components declined below that of the blend ratio of the nonaged lure by the start of the fifth week, indicating that (*Z,E*)-9,12-tetradecadienyl acetate emissions declined faster than (Z)-9-tetradecen-1-ol. Changes in blend might contribute to the reduction in trap captures after the lure is aged for 4 wk, but the emission of (Z)-9-tetradecen-1-ol seems to play a more important role in governing the lure's attractiveness to adult male beet armyworms.

Because 3–4-wk-old lures attracted fewer beet armyworms, trap captures with lures ≥3 wk old should be interpreted differently than when less-aged lures are deployed. The loss in the lure's capacity to attract male beet armyworms indicates a loss in effectiveness, and because an adjustment to trap capture interpretation becomes necessary, the lure is also less efficient for monitoring purposes. Because the trap can still attract moths more than the control when aged 3–4 wk under tropical and subtropical conditions, the lure remains "effective" at collecting adult male beet armyworms, although at reduced capacity.

The low response of moths to 3–4-wk-old lures, and the reduced emission of (Z)-9-tetradecen-1-ol by 4-wk-old lures, together suggest that further aging would likely reduce moth response by >80%. Efficiency for monitoring was maintained for up to 3 wk, and the response by moths was substantially diminished when 3–4-wk-old lures were used. Our findings will assist in the development of a trapping system for assessing beet armyworm activity under tropical and subtropical conditions that exist in Africa, Asia, Australia, and North and South America. Also, with the possibility of secondary beet armyworm outbreaks during boll weevil eradication efforts in the tropics and subtropics (Summy et al. 1996), assessment of beet armyworm populations might become increasingly important.

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