Effect of Starch-Based Corn Rootworm (Coleoptera: Chrysomelidae) Baits on Selected Nontarget Insect Species: Influence of Semiochemical Composition

Thomas J. Weissling  
*University of Nebraska-Lincoln*, twweissling2@unl.edu

Lance J. Meinke  
*University of Nebraska-Lincoln*, lmeinke1@unl.edu

Kandy A. Lytle  
*University of Nebraska-Lincoln*

Follow this and additional works at: [http://digitalcommons.unl.edu/entomologyfacpub](http://digitalcommons.unl.edu/entomologyfacpub)
ABSTRACT Various starch-encapsulated semiochemical-insecticide formulations, developed for potential use in adult corn rootworm (Diabrotica spp.) management programs, were evaluated in the laboratory and field for effectiveness on corn rootworm beetles: a carabid, Harpalus pennsylvanicus DeGeer; and a coccinellid, Coleomegilla maculata lengi Timberlake. Carbaryl was formulated in pregelatinized starch matrices along with Diabrotica-specific semiochemicals. The specific combination of feeding-gustatory stimulants encapsulated within or coating the outside of starch granules significantly influenced effectiveness. All starch formulations containing feeding-gustatory stimulants effectively killed Diabrotica virgifera virgifera LeConte adults in laboratory and field bioassays. However, H. pennsylvanicus and C. m. lengi mortality was greatly reduced when presented with starch granules coated with buffalo gourd (Cucurbita foetidissima H.B.K.) root powder (contains cucurbitacin E, I, and E-glycoside) or purified cucurbitacin I. Cucurbitacin I and component(s) of buffalo gourd root powder appear to be C. m. lengi and H. pennsylvanicus antifeedants. In the field, significantly more C. m. lengi and D. v. virgifera were collected at traps baited with pollen-coated than root powder-coated starch granules. When granules were broadcast over plants, mortality of C. m. lengi was greater in plots receiving pollen-coated than root powder-coated granules whereas the opposite was observed for corn rootworm beetles. Data suggest that to optimize the effectiveness of starch baits against D. v. virgifera and to minimize adverse effects on C. m. lengi and H. pennsylvanicus, granules coated with cucurbitacin rather than with starch or pollen should be used in corn rootworm management programs.

KEY WORDS Insecta, corn rootworms, nontarget species, semiochemicals

Effect of Starch-Based Corn Rootworm (Coleoptera: Chrysomelidae) Baits on Selected Nontarget Insect Species: Influence of Semiochemical Composition

THOMAS J. WEISSLING, LANCE J. MEINKE, AND KANDY A. LYTLE

Department of Entomology, University of Nebraska, Lincoln, Nebraska 68583

Baits containing semiochemicals offer several possible advantages for use in pest management systems. Among these is the potential to selectively attract a pest or pest complex to a bait while minimizing adverse effects on nontarget species (Shor-ey 1981). The corn rootworm species complex (Diabrotica spp.) has a well-established array of chemical messengers (Ladd et al. 1983, Lampman & Metcalf 1987, Lampman et al. 1987, Metcalf 1986, Metcalf & Lampman 1989) that make it an ideal system for demonstrating the potential of this concept. Diabrotica spp. exhibit species-specific attraction to several related phenylpropanoids (Ladd et al. 1983, Lampman et al. 1987, Metcalf & Lampman 1989) and benzoid compounds (Lampman et al. 1987, Lampman & Metcalf 1987). In addition, cucurbitacins (oxygenated tetracyclic triterpenes) have been identified as compounds that arrest movement and initiate compulsive feeding when detected by diabroticite beetles (Chambliss & Jones 1966, Howe et al. 1976, Metcalf et al. 1980, Metcalf 1986) but tend to repel or deter feeding by non-adapted species (Metcalf et al. 1980, Nielson et al. 1977). We have used starch matrices, originally developed by Trimnell et al. (1982) and Dunkle & Shasha (1988) as herbicide and Bacillus thuringiensis Berliner carriers, respectively, to create controlled release semiochemical-insecticide baits for possible use in adult corn rootworm management programs. Initial studies have shown that D. virgifera virgifera LeConte sex pheromone (racemic [Meinke et al. 1989]) and various plant-derived corn rootworm attractants (Weissling et al. 1989) could be successfully encapsulated in starch matrices. Starch matrix formulations have subsequently been developed that contain attractants, feeding-gustatory stimulants (cucurbitacins and pollen), and minute amounts of insecticide, which will attract and kill D. v. virgifera over time in field corn (Weissling & Meinke 1991).

Field trials conducted to determine the effect of these starch formulations on corn rootworm beetles and selected nontarget insect species indicated that the carabid Harpalus pennsylvanicus DeGeer and the coccinellid Coleomegilla maculata lengi Timberlake will feed on starch granules, and that mortality may occur after feeding (Weissling & Meinke...
granules. In the first bioassay, buffalo gourd root powder and pollen were incorporated into the matrix; starch-coated, with root powder and pollen incorporated into the matrix; pollen-coated, with root powder incorporated into the matrix; root powder-coated, with pollen incorporated into the matrix; starch-coated blank granules (no semiochemical or insecticide incorporated into the matrix); and an untreated check (no granules).

Starch granules (0.85–2 mm diameter, 100 mg per treatment per replication) were placed in glass Petri dishes (15 by 60 mm) that were placed in the bottom of cylindrical plastic containers (850 cm²). Each arena contained a water-moistened cotton wick and was enclosed with a plastic lid that had a circular vent (28 cm²) covered with nylon mesh. Ten laboratory-reared nondiapausing larvae of D. v. virgifera (colony originally obtained from French Agricultural Service, Lamberton, Minn.) were introduced into each arena. Containers were then arranged in a completely random design (three replications) and held at 23 ± 1°C, with a photoperiod of 14:10 (L:D). D. v. virgifera mortality was determined at 24 h.

The experiment was repeated with starch formulations that had buffalo gourd root powder and pollen incorporated at 37.5 and 5 mg/g matrix, respectively. Treatments included granules that were starch-coated, with root powder and pollen incorporated into the matrix; pollen-coated, with root powder incorporated into the matrix; root powder-coated, with pollen incorporated into the matrix; starch-coated blank granules (no semiochemical or insecticide incorporated into the matrix); and an untreated check.

Culex pipiens f. molestus adults were collected in the field and maintained in the laboratory on a diet of Musca domestica L. larvae, and various aphid species, respectively, until used in bioassays. Treatments included granules (0.60–0.85 mm diameter) that were starch-coated, with root powder and pollen incorporated into the matrix; root powder-coated, with pollen incorporated into the matrix; starch-coated blank granules (no semiochemicals or insecticide incorporated into the matrix); and an untreated check.

Coleomegilla maculata lengi and H. pennsylvanicus Bioassay. The effect of different corn rootworm feeding stimulant combinations was evaluated on two nontarget species. H. pennsylvanicus and C. m. lengi adults were collected in the field and maintained in the laboratory on a diet of Musca domestica L. larvae, and various aphid species, respectively, until used in bioassays. Treatments included granules (0.60–0.85 mm diameter) that were starch-coated, with root powder and pollen incorporated into the matrix; root powder-coated, with pollen incorporated into the matrix; starch-coated blank granules (no semiochemicals or insecticide incorporated into the matrix); and an untreated check.

A separate bioassay was conducted for each non-target species. Test arenas were plastic Petri dishes (15 by 100 mm) for H. pennsylvanicus and 850 cm² plastic containers (as described for D. v. virgifera) for C. m. lengi. Each arena contained a water-moistened cotton wick. Treatments were added to H. pennsylvanicus and C. m. lengi arenas at 50 and 100 mg per arena, respectively. One H. pennsylvanicus or 10 C. m. lengi were introduced into appropriate arenas. Test arenas for both species were arranged separately in a completely random design (H. pennsylvanicus, 14 replications; C. m. lengi, four replications) and were held at 26 ± 1.3°C, with a photoperiod of 14:10 (L:D). Mortality was recorded at 24 h.

Materials and Methods

Carbaryl and various plant-derived compounds, identified as Diabrotica semiochemicals, were used to make starch formulations from pregelatinized starch (Dunkle & Shasha 1988) for use in all experiments. Unless otherwise stated, compounds encapsulated within all test formulations were carbaryl, and the TIC mixture (a volatile corn rootworm attractant composed of a 1:1:1 mixture of 1,2,4-trimethoxybenzene, indole, and trans-cinnamic acid) was added to each test formulation. Carbaryl and the TIC mixture were incorporated into starch matrices at 37.5 and 5 mg/g matrix, respectively. When used to coat starch granules, buffalo gourd root powder from Cucurbita foetidissima H.B.K. root powder (contains cucurbitacins E, I, and E-glycoside [Metcalf et al. 1982]), and pollen (C.C. Pollen Company, Scottsdale, Ariz.). Carbaryl and root powder from the same source were used in all experiments but cucurbitacin content was not quantified. However, Metcalf et al. (1982) have reported that the amount of cucurbitacin E, I, and E-glycoside in fresh C. foetidissima root was 0.28, 1.72, and 0.59 mg/g, respectively. Buffalo gourd root powder and pollen were incorporated into starch matrices at 37.5 and 5 mg/g matrix, respectively (unless otherwise stated). When used to coat starch granules, buffalo gourd root powder and pollen were added to excess.

Laboratory observations have indicated that even when insects are confined within small arenas containing starch-encapsulated semiochemical-insecticide formulations, mortality will occur only after ingestion of granules (T.J.W. & L.J.M., unpublished data). Therefore, all experiments in this study were designed to assay the effect of various feeding-gustatory stimulant combinations placed within or on the outside of starch granules using insecticide induced mortality as an indicator that feeding had occurred.

Diabrotica v. virgifera Bioassay. Laboratory bioassays were used to evaluate the effect of starch formulations on D. v. virgifera adults when different feeding-gustatory stimulant combinations were incorporated into or placed on the outside of granules. In the first bioassay, buffalo gourd root powder and pollen were incorporated into the starch formulations at 10 and 2.5 mg/g matrix, respectively. Treatments included granules that were starch-coated, with root powder incorporated into the matrix; starch-coated, with pollen incorporated into the matrix; starch-coated, with root powder and pollen incorporated into the matrix; pollen-coated, with root powder incorporated into the matrix; root powder-coated, with pollen incorporated into the matrix; starch-coated blank granules (no semiochemical or insecticide incorporated into the matrix); and an untreated check (no granules).
Table 1. Mortality of D. v. virgifera from ingestion of pregelatinized starch granules formulated with different combinations of feeding-gustatory stimulants

<table>
<thead>
<tr>
<th>Treatment*</th>
<th>% Mortality (24 h), ± SEM</th>
<th>Bioassay 1</th>
<th>Bioassay 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coating</td>
<td>Within</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Starch</td>
<td>BGRP*</td>
<td>96.7 ± 3.3a</td>
<td>—</td>
</tr>
<tr>
<td>Starch</td>
<td>Pollen</td>
<td>93.3 ± 6.7a</td>
<td>—</td>
</tr>
<tr>
<td>Starch</td>
<td>BGRP &amp; Pollen</td>
<td>100.0 ± 0.0a</td>
<td>96.7 ± 3.3a</td>
</tr>
<tr>
<td>Pollen</td>
<td>BGRP</td>
<td>100.0 ± 0.0a</td>
<td>96.7 ± 3.3a</td>
</tr>
<tr>
<td>Blank granules</td>
<td>13.3 ± 6.7b</td>
<td>0.0 ± 0.0b</td>
<td></td>
</tr>
<tr>
<td>No granules</td>
<td></td>
<td>16.7 ± 3.9b</td>
<td>0.0 ± 0.0b</td>
</tr>
</tbody>
</table>

Means within columns followed by the same letter are not significantly different (least significant difference, L.S.D., p ≤ 0.05).

* Technical carbaryl and TIC (a 1:1:1 mixture of 1,2,4-trimethylbenzothiazoline, indole, and trans-cinnamaldehyde) were added to starch formulations at 7.5 mg and 1 mg (each)/g matrix, respectively; coating, outside of matrix; within, encapsulated within matrix.

BGRP: Buffalo gourd (C. foetidissima H.B.K.) root powder added to the starch matrix at 10 (bioassay 1) and 37.5 (bioassay 2) mg/g.

Pollen was added to starch formulations at 2.5 (bioassay 1) and 5.0 (bioassay 2) mg/g.

An additional bioassay was done to determine if an alternate food source presented to C. m. lengi along with starch formulations influenced mortality. The experimental design was the same as that previously described for C. m. lengi except that 57 ± 3 live greenbugs, Schizaphis graminum (Ron-dani), were placed in each arena 30 min before introduction of C. m. lengi beetles. Cucurbita foetidissima root contains several compounds in addition to cucurbitacin (i.e., starch, lignins, and fatty acids [Berry et al. 1978]). Thus, additional bioassays were conducted to determine if purified cucurbitacin would elicit the same responses by nontarget species as observed with buffalo gourd root powder. Arenas used for each nontarget species were identical to those previously described for H. pennsylvanicus. Treatments included starch granules (0.60–4.75 mm diameter) that were root powder-coated, with pollen incorporated into the matrix; and pollen-coated, with root powder incorporated into the matrix. Two grams of granules (0.85–2 mm diameter) were placed in plastic Petri dish bottoms (15 by 100 mm) that were taped to the upper surface of adhesive-free trap bottoms. Traps were attached to plants at corn ear height.

Within a 2.25-ha field, treatments were arranged in a randomized complete block design (four replications) and each block (separated by 6.1 m) consisted of four traps spaced 6.1 m apart. All dead or moribund adult D. v. virgifera, D. barberi Smith & Lawrence, and C. m. lengi found in traps or on the soil surface directly beneath traps were collected daily for 10 d. The number of each species collected at each trap was determined, and sex ratios were determined for D. v. virgifera and D. barberi. Corn ('Pioneer 3377') was in the dough stage at the beginning of the experiment (R4 stage [Ritchie & Hanway 1984]). To estimate adult corn rootworm and C. m. lengi population levels, whole plant beetle counts (Tollefson 1986) were taken on 10 (23 August) and 20 (2 September) randomly selected plants (except those near traps) within the field.

Broadcast Study. Two starch-based formulations coated with different feeding stimuli (four replications) were compared in a field assay (29 August–3 September 1989) to determine the relative effectiveness of each formulation on adult corn rootworms and two nontarget species. Treatments included starch granules (0.60–4.75 mm diameter) that were root powder-coated, with pollen incorporated into the matrix; and pollen-coated, with root powder incorporated into the matrix. Plots (separated by 3 m) were arranged in a completely random design (four replications) within a 1.13-ha field. Each plot (2.9 m²) included two adjacent corn rows. Treatments were applied to plots on 28 August by sprinkling 4 g (13 kg/ha) of granules by hand evenly over plants in both rows. Plants at the time of application had just completed flowering ('Pioneer 3377' R2 stage [Ritchie & Hanway 1984]). Efficacy of treatments was determined daily by collecting all dead or moribund adult D. v. virgifera, D. barberi, D. undecimpunctata howardi Barber, H. pennsylvanicus, and C. m. lengi within plots on plants and on the soil surface.

To estimate adult corn rootworm and C. m. lengi populations in the test field, whole plant beetle counts were taken on 15 randomly selected plants (excluding those within plots) on 29 August and 3 September.

Statistical Analyses. All data (except in tests where purified cucurbitacin I was used) were subjected to angular arcsine √x (laboratory studies) and square root (x + 0.5) (field studies) transfor-
Table 2. Mortality (x ± SEM) of C. m. lengi and H. pennsylvanicus from ingestion of pregelatinized starch granules formulated with different combinations of feeding-gustatory stimulants

| Treatment* | Coating | Within | H. pennsylvanicus | C. m. lengi | C. m. lengi
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Starch</td>
<td>BGRP* &amp; Pollen*</td>
<td>100.0 ± 0.0a</td>
<td>100.0 ± 0.0a</td>
<td>97.5 ± 2.5a</td>
</tr>
<tr>
<td></td>
<td>Pollen</td>
<td>BGRP</td>
<td>71.4 ± 12.5b</td>
<td>97.5 ± 2.5a</td>
<td>100.0 ± 0.0a</td>
</tr>
<tr>
<td></td>
<td>BGRP</td>
<td>Pollen</td>
<td>35.7 ± 13.3c</td>
<td>47.5 ± 1.0b</td>
<td>15.0 ± 6.5b</td>
</tr>
<tr>
<td></td>
<td>No granules</td>
<td></td>
<td>0.0 ± 0.0d</td>
<td>0.0 ± 0.0c</td>
<td>0.0 ± 0.0c</td>
</tr>
</tbody>
</table>

Means within columns followed by the same letter are not significantly different (least significant difference, F = 0.05).

* Technical carbaryl and TIC (a 1:1 mixture of 1,2,4-trimethoxybenzene, inode, and trans-cinnamaldehyde) were added to starch formulations at 7.5 mg and 1 mg (each)/g matrix, respectively; coating, outside of matrix; within, encapsulated within matrix.

** An average of 57 live greenbugs (S. graminum) were added to each arena just before introduction of C. m. lengi.

† BGRP: Buffalo gourd (C. foetidissima H. B. K.) root powder added to starch formulations at 37.5 mg/g.

‡ Pollen was added to starch formulations at 5.0 mg/g.

mortality and were analyzed by analysis of variance (ANOVA) (SAS Institute 1985). Untransformed means are presented in tables. Analyses were conducted for treatment effects over the entire experimental period (two-way ANOVA [laboratory studies] and split-plot design [field studies]). Least significant difference tests (SAS Institute 1985) were used for mean separation where significant (P < 0.05) treatment effects occurred. Mortality data in tests where purified cucurbitacin I was used indicated that significant differences occurred among treatments (C. m. lengi: F = 9.41; df = 2; P = 0.003; H. pennsylvanicus: F = 10.17; df = 2; P = 0.005). C. m. lengi and H. pennsylvanicus mortality in arenas containing starch-coated granules was significantly greater than mortality in the other treatments (percentage mortality [x ± SEM] starch-coated granules: C. m. lengi: 95.0 ± 5.0; H. pennsylvanicus: 57.1 ± 20.0). No mortality was observed in arenas containing curcurbitacin I-coated granules or in the untreated check at 24 h.

Diabrotica v. virgifera Bioassay. D. v. virgifera mortality attributable to ingestion of starch formulations ranged from 93 to 100% after 24 h (Table 1). Statistical analyses indicated significant treatment effects for both bioassays (bioassay 1: F = 92.93; df = 6,12; P < 0.01; bioassay 2: F = 1,321.0; df = 4,8; P < 0.01). D. v. virgifera mortality in both bioassays was significantly greater in treatments with insecticide incorporated into the formulations than in treatments with blank granules or in the untreated check. There were no significant differences in D. v. virgifera mortality among formulations that contained insecticide (Table 1).

Coleomegilla maculata lengi and H. pennsylvanicus Bioassay. H. pennsylvanicus mortality varied significantly among treatments (F = 26.79; df = 3,39; P < 0.01). H. pennsylvanicus mortality in arenas containing starch formulations was significantly greater than in the untreated check (Table 2). However, mortality was significantly greater in arenas with starch- and pollen-coated formulations than in arenas with the root powder-coated formulation. Significantly greater H. pennsylvanicus mortality was observed in arenas that contained starch-coated granules than in arenas with pollen-coated granules (Table 2).

Coleomegilla maculata lengi mortality also differed significantly among treatments (without aphids: F = 75.42; df = 3,9; P < 0.01, with aphids: F = 249.4; df = 3,9; P < 0.01) (Table 2). In both bioassays, C. m. lengi mortality in arenas with starch granules was significantly greater than in arenas without granules. In addition, C. m. lengi mortality in arenas containing starch- or pollen-coated granules was significantly greater than in arenas with root powder-coated granules (Table 2).

Analyses of D. v. virgifera and H. pennsylvanicus bioassays where cucurbitacin I-coated granules were used indicated that significant differences occurred among treatments (C. m. lengi: F = 9.41; df = 2; P = 0.003; H. pennsylvanicus: F = 10.17; df = 2; P = 0.005). C. m. lengi and H. pennsylvanicus mortality in arenas containing starch-coated granules was significantly greater than mortality in the other treatments (percentage mortality [x ± SEM] starch-coated granules: C. m. lengi: 95.0 ± 5.0; H. pennsylvanicus: 57.1 ± 20.0). No mortality was observed in arenas containing curcurbitacin I-coated granules or in the untreated check at 24 h.

**Trapping Study.** Total rainfall received during the experimental period was 0.8 cm on 2 September (measured 200 m from the study site). No C. m. lengi beetles were detected during whole-plant counts and the D. v. virgifera and D. barberi population levels declined during the experimental period (beetles per plant [x ± SEM]: D. v. virgifera: 23 August, 0.8 ± 0.20; 2 September, 0.0 ± 0.0; D. barberi: 23 August, 0.10 ± 0.10; 2 September, 0.0 ± 0.0).

Analysis of trap catch over the entire experimental period indicated that statistical differences occurred among treatments (D. v. virgifera: F = 13.06; df = 3,9; P < 0.01, D. barberi: F = 88.61; df = 3,9; P < 0.01, C. m. lengi: F = 14.57; df = 3,9; P < 0.01), and among dates (D. v. virgifera: F = 27.55; df = 9,81; P < 0.01, D. barberi: F = 8.93; df = 9,81; P < 0.01, C. m. lengi: F = 2.25; df = 9,81; P < 0.03). Significant treatment x date interactions were also observed (D. v. virgifera: F = 5.23; df = 27,81; P < 0.01, D. barberi: F = 3.79; df = 27,81; P < 0.01).

Significantly more D. v. virgifera were collected at traps baited with pollen-coated starch granules than at traps baited with any other treatment whereas significantly more D. barberi were collected at traps baited with starch-coated granules.
than at traps baited with any other treatment (Table 3). The mean number of *D. v. virgifera* collected at traps baited with starch-coated granules was significantly greater than the mean number collected at traps baited with blank granules. The mean number of *D. barberi* collected at traps baited with root powder-coated granules was significantly greater than the mean number collected at traps baited with pollen-coated granules. In addition, significantly more *D. barberi* were collected at traps baited with pollen-coated granules than at traps baited with blank granules. In all cases, more male *D. barberi* were collected at traps baited with pollen-coated granules than at traps baited with any other treatment (Table 3).

The *D. v. virgifera* female-to-male ratio varied among treatments but females were always more numerous than males. In all cases, more male *D. barberi* were caught in traps than females (Table 3).

**Broadcast Study.** Total rainfall received during the experimental period was 0.8 cm on 2 September (measured 300 m from the study site). *D. v. virgifera, D. barberi, D. u. howardi,* and *C. m. lengi* population levels decreased during the experimental period (mean per plant [± SEM]) *D. v. virgifera: 29 August, 2.40 ± 0.58, 3 September, 1.13 ± 0.39; D. barberi: 29 August, 0.93 ± 0.28, 3 September, 0.33 ± 0.13; D. u. howardi: 29 August, 0.07 ± 0.07, 3 September, 0.00 ± 0.00; C. m. lengi: 29 August, 0.33 ± 0.13, 3 September, 0.07 ± 0.07).

The analysis conducted on mortality of each species over the entire experimental period indicated that statistical differences occurred among treatments (*D. u. howardi: F = 26.98; df = 1,3; P < 0.01, C. m. lengi: F = 11.66; df = 1,3; P < 0.04), and among dates (*D. v. virgifera: F = 8.90; df = 4,12, P < 0.01, D. barberi: F = 18.56; df = 4,12, P < 0.01, C. m. lengi: F = 13.48; df = 4,12, P < 0.01). Significant treatment × date interactions were also observed (*D. barberi: F = 4.86; df = 4,12, P < 0.01, C. m. lengi: F = 9.62; df = 4,12, P < 0.01). *H. pennsylvanicus* were collected from the treated plots but levels were low and therefore were not included in the analyses.

Significantly fewer *C. m. lengi* beetles were collected from plots treated with root powder-coated granules than plots treated with pollen-coated granules (Table 4). In all cases, more corn rootworm beetles were collected from plots treated with root powder-coated granules, than from plots that received pollen-coated granules, but differences were significant only for *D. u. howardi* (Table 4). Female-to-male ratios, determined from collected dead corn rootworm beetles, were skewed towards females for *D. v. virgifera,* and males for *D. barberi* and *D. u. howardi.*

**Discussion.** All starch formulations evaluated were effective as *D. v. virgifera* mortality agents when feeding-gustatory stimulants were present either within or coating the granules. However, the specific combination of feeding-gustatory stimulants appears to be an important factor in determining whether nontarget species accept or reject starch granules as a potential food source.

*Diabrotica v. virgifera* mortalities in laboratory bioassays and in the broadcast study were similar among starch granule treatments with insecticide. However, *D. v. virgifera* mortality varied among treatments in the trapping study. The trapping study was conducted during the postflowering phenology stage when corn rootworm populations were low and decreased through time. The amount of preferred food (i.e., fresh or green silks and pollen, Lance & Fisher 1987, Naranjo & Sawyer 1987) available to corn rootworm beetles is limited during this period, and *D. v. virgifera* beetles may have perceived pollen-coated granules placed in traps as a potential food source. Reasons why *D. barberi* preferred starch-coated granules over other granules are unclear. The broadcast study was conducted in a late-planted field where scattered flowering corn plants (sources of quality food) were still present and corn rootworm populations were relatively high. Pollen-coated granules placed in this

### Table 3. Mean number ± SEM of *D. v. virgifera, D. barberi,* and *C. m. lengi* collected per trap per day for 10 d at traps baited with pregelatinized starch granules formulated with different combinations of feeding-gustatory stimulants, 1989

<table>
<thead>
<tr>
<th>Coating</th>
<th>Within</th>
<th><em>D. v. virgifera</em></th>
<th><em>D. barberi</em></th>
<th><em>C. m. lengi</em></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>No.</td>
<td>± SEM</td>
<td>No.</td>
<td>± SEM</td>
</tr>
<tr>
<td>Starch &amp; Pollen</td>
<td>BCRP, Pollen</td>
<td>5.8 ± 0.6b</td>
<td>4.2</td>
<td>2.4 ± 0.5a</td>
</tr>
<tr>
<td>Pollen</td>
<td>BCRP</td>
<td>14.2 ± 1.7a</td>
<td>26.5</td>
<td>0.8 ± 0.2c</td>
</tr>
<tr>
<td>Pollen</td>
<td>Pollen</td>
<td>8.9 ± 1.2b</td>
<td>10.5</td>
<td>1.4 ± 0.3b</td>
</tr>
<tr>
<td>Starch</td>
<td>Pollen</td>
<td>0.2 ± 0.1c</td>
<td>5.0</td>
<td>0.2 ± 0.0d</td>
</tr>
</tbody>
</table>

Means within columns followed by the same letter are not significantly different (least significant difference, *P* ≤ 0.05).

a Technical carbachol and TIC (a 1:1:1 mixture of 1,2,4-trimethoxybenzene, indole, and trans-cinnamaldehyde) were added to starch formulations at 7.5 mg and 1 mg (each)/g matrix, respectively; coating, outside of matrix; within, encapsulated within matrix.

b *C. m. lengi:* mean number of female corn rootworms per mean number of male corn rootworms collected from traps.

c BCRP: Buffalo gourd (*C. foetidissima* H.B.K.) root powder added to starch formulations at 37.5 mg/g.
d Pollen was added to starch formulations at 5.0 mg/g.
field may not have been as apparent to corn rootworm beetles as a potential food source as granules in the trapping study because of possible competition from flowering corn plants. Decreasing beetle populations and variability in the amount of food present in the fields may have contributed to the significant interactions observed through time in both experiments.

Mortality of *H. pennsylvanicus* and *C. m. lengi* in laboratory bioassays was greatly reduced in treatments where buffalo gourd root powder or cucurbitacin I was used to coat granules. This suggests that even in a no-choice situation, where hunger could potentially reduce diet choice selectivity over time (Dethier 1982), cucurbitacin I and a component of buffalo gourd root powder (presumably cucurbitacin E, I, or E-glycoside) are adult *C. m. lengi* and *H. pennsylvanicus* antifeedants as defined by Frazier (1986). Cucurbitacins are known feeding stimulants for diabroticites (Chambliss & Jones 1966) but also deter feeding by such insects as the chrysomelid beetles *Phyllotreta nemorum* L. (Nielson et al. 1977) and *Cerotoma trifurcata* (Forster) (Metcalf et al. 1980) when applied to host plant tissues.

Results from field studies suggest that when given a choice, *C. m. lengi* will feed more readily on pollen-coated than starch- or buffalo gourd root powder-coated starch formulations. Pollen is an accepted food of most coccinellids (Hodek 1967, Conrad 1959) and like *D. v. virgifera*, *C. m. lengi* may have perceived pollen-coated granules as a potential food source. Pollen could have been especially apparent to *C. m. lengi* during the trapping study because of the advanced corn phenology and the absence of alternate food sources (i.e., aphids) in the field (T.J.W., unpublished data).

Alternate food sources available to nontarget species could potentially decrease starch formulation induced mortality by reducing hunger and subsequent encounters with granules. When released into arenas with aphids, *C. m. lengi* beetles randomly searched the enclosures and ingested acceptable food sources as they were encountered (L.J.M. & K.A.L., unpublished data). *C. m. lengi* mortality in arenas containing aphids and buffalo gourd root powder-coated granules was substantially lower than mortality in the bioassay where root powder-coated granules were presented to *C. m. lengi* without the addition of aphids (Table 2). This suggests that the presence of an alternate food source may have increased the likelihood of *C. m. lengi* beetles rejecting root powder-coated granules as a potential food source. *C. m. lengi* mortality at 24 h in other treatments appeared to be unaffected by the addition of aphids into arenas (Table 2).

Maintenance of nontarget species (especially beneficial species) populations after implementation of control tactics may be of great importance, especially when outbreaks of secondary pests are a concern. Data presented here indicate that starch granules formulated with different feeding-gustatory stimulants have potential for manipulating the feeding preference of nontarget species while maintaining efficacy against a target pest. Specifically, to optimize the effectiveness of starch baits against *D. v. virgifera* and to minimize adverse effects on *C. m. lengi* or *H. pennsylvanicus*, starch-based granules coated with cucurbitacin would be preferred over starch- or pollen-coated granules for use in corn rootworm management programs.

### Acknowledgment

We thank Mike Barnhart, Jim Brown, and Rod Hansen for laboratory and field assistance, and Lisa Silberman for providing greenbugs. This research was supported by the Nebraska Corn Development, Utilization, and Marketing Board, and the University of Nebraska Agricultural Experiment Station, Project 17-043. This article is paper no. 9289 of the journal series of the Nebraska Agricultural Research Division and contribution no. 734 of the Department of Entomology, University of Nebraska—Lincoln.

### References Cited


Conrad, M. S. 1959. The spotted lady beetle, *Coleo-...
meigilla maculata (DeGeer), as a predator of European corn borer eggs. J. Econ. Entomol. 52: 843-847.


Received for publication 24 July 1980; accepted 22 March 1991.