Development of a Toxic Bait for Control of Eastern Lubber Grasshopper (Orthoptera: Acrididae)

KATHRYN A. BARBARA[1] and JOHN L. CAPINERA

Department of Entomology and Nematology, University of Florida, Gainesville, FL 32611

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ABSTRACT This study assessed baits for eastern lubber grasshopper, *Romalea guttata* (Houttuyn). When offered a choice among several grain-based baits (rolled oats, wheat bran, oat bran, yeast, corn meal, cornflakes) and vegetable oils (canola, corn, peanut, soybean), eastern lubber grasshopper adults preferred bait consisting of wheat bran carrier with corn oil as an added phagostimulant. Other carriers were accepted but consumed less frequently. Discrimination by eastern lubber grasshoppers among oils was poor. Similarly, addition of flavorings (peppermint, anise, lemon, banana) resulted in few significant effects. The carbaryl, wheat bran, and oil bait developed in this study was effective at causing eastern lubber grasshopper mortality in field-cage studies. Significant mortality occurred even though grasshoppers had to locate dishes of bait in a large cage, and could feed on daylilies, or grass growing through the bottom of the cage, rather than on the bran flakes. Consumption of as little as a single carbaryl-treated bran flake could induce mortality, although individuals varied greatly in their susceptibility. The bait matrix developed in this study was readily consumed when in the presence of some plant species. We expect that wheat bran and corn oil bait would be most effective as protection for less preferred plants (tomato, pepper, eggplant, leek, parsley, fennel, daylily, lily of the Nile, and canna lily) because baits were readily consumed in the presence of these plants. Plants that are readily consumed in the presence of bait (preferred plants) included butter crunch lettuce, carrot, yellow squash, cauliflower, collards, green onion, chive, cucumber, cabbage, cantalope, endive, red leaf lettuce, society garlic, caladium, and amaryllis. Baits are likely to be less effective in the presence of such plants. On average, vegetables in Solanaceae (i.e., tomato, pepper, and eggplant) and Apiaceae (i.e., fennel and parsley) elicited high levels of bait-feeding activity, indicating that these vegetables were not highly preferred. The plants tested from Liliaceae, Cucurbitaceae, Asteraceae, and Brassicaceae elicited an intermediate-to-low level of bait feeding.

KEY WORDS grasshopper, carbaryl, oil, food-based bait, integrated pest management (IPM)

Many studies have examined the effectiveness of insecticide-treated baits as preventative agents against grasshopper damage (Roberts 1937, Drake and Tate 1938, Farrar and Flint 1938, Faure and Jacot-Guillarmod 1940, Shotwell 1942, Foster et al. 1979, Onsager et al. 1980a, b, Mukerji et al. 1981, Mukerji and Ewen 1984, Foster et al. 1998, Capinera and Squitier 2000). Very little research, however, has been conducted on the effectiveness of baits against the eastern lubber grasshopper, *Romalea guttata* (Houttuyn). The eastern lubber grasshopper is a pest of home gardens and, occasionally, commercial crops of the southeastern United States. The eastern lubber grasshopper is one of only a few grasshopper species that damage agricultural crops in the southeastern United States. Arid and semiarid areas of western North America, in contrast, frequently experience dramatic increases in abundance of numerous grasshopper species, with subsequent crop damage (Capinera 1993). Consequently, most research on grasshopper biology and management does not include *R. guttata,* which is geographically restricted to the southeastern United States.

Bait formulations provide several advantages over other insecticide application methods. Baits greatly reduce problems encountered with runoff and drift from liquid and dust insecticide formulations (Jech et al. 1993). Baits are useful when control programs are conducted near water, or in areas where threatened and endangered species occur, and where preservation of beneficial species of arthropods is important. When baits are applied little dispersion occurs, unlike liquid or dust forms of insecticides. Also, using baits substantially reduces the overall amount of active ingredient needed and therefore reduces the amount of insecticide present in the environment. Grasshopper baits are rapidly consumed; hence, the insecticide spends less time in the environment (Onsager et al. 1980a). Baits often are specific to the target organism,

[1] E-mail: kbarbara@ufl.edu.

or at least provide greater selectivity than liquids and dusts.

The efficacy of baits often depends on the palatability of its components. It was therefore necessary to evaluate several materials for palatability and phagostimulatory properties and their effectiveness. Wheat bran has been previously shown to be an acceptable bait matrix for several species of grasshoppers and other insect species with similar feeding preferences (Cooley et al. 1918, Farrar et al. 1938, Shotwell 1942, Martin 1980, Kepner and Yu 1987, Capinera and Squitier 2000). Oils and flavor extracts have sometimes been added to bait matrices and have proven effective in stimulating grasshopper feeding (Parker 1922, Shotwell 1942, Swenk and Wehr 1923, Kepner and Yu 1987, Lockwood et al. 2001).

The objective of our study was to compare a variety of potential baits and phagostimulants in an attempt to identify an inexpensive, uncomplicated bait formulation that could be used to control the eastern lubber grasshopper. In this study the preferred bait matrix of the eastern lubber grasshopper and the palatability of potential additives were determined. Also, the effectiveness of wheat bran and corn oil bait was tested in the presence of common plants found in many Florida yards and gardens. Last, carbaryl was added to the bait matrix and assessed under field cage conditions.

Materials and Methods

Bioassays were conducted using laboratory-reared and field-collected eastern lubber grasshoppers. Laboratory cultures of this species are maintained on a diet of romaine lettuce and dry diet (soybean meal, wheat flour, and flaky wheat bran in a ratio of 1:1:2 by weight) as described by Henry (1985). The laboratory culture of this species was started from field-collected grasshoppers from Florida ≤2 yr ago and supplemented throughout the study with recently collected individuals. The field-collected grasshoppers were collected from areas in Alachua and Lee counties, FL, during spring and summer 2000 and 2001. Both laboratory cultures and field-collected grasshoppers were maintained on the same diet in the laboratory at 30–32°C and under a photoperiod of 14:10 (L:D) h, with free access to water. Both colonies were indiscriminately used in all studies.

Matrix Preference. Six different grain-based food sources were evaluated in this study. Petri dishes were filled with 10 g each of rolled oats (Publix Supermarkets, Inc., Lakeland, FL), wheat bran flakes (Tree of Life, St. Augustine, FL), oat bran (Heartland Brands, Collegedale, TN), yeast (Tree of Life, St. Augustine, FL), corn meal (Dixie-Lilly Foods, Nashville, TN), and corn flakes (Grainfield's, Wheatabix, Clinton, MA). Five male and five female adult eastern lubber grasshoppers were held in cages 0.3 m on each side, cultured at 30°C, and exposed to light from fluorescent and incandescent light bulbs for 14 h. The grasshoppers were allowed to feed on the test material for 72 h. Spilled test material was recovered from the cage and the final weight was recorded. The food source was weighed before and after exposure to the grasshoppers. Five replicates of 10 adult grasshoppers per cage were evaluated, with different starting times (days) serving as the basis for replication. The amount of the food source consumed was measured in grams eaten and as a proportion of the total amount eaten per replicate. The grasshoppers were provided with no other food or source of moisture during this and all subsequent tests.

After the six food sources were evaluated, the three most attractive food sources, rolled oats, oat bran, and wheat bran (corn meal was eliminated from further tests because its small size made it difficult to work with), were again evaluated in a separate test conducted as described below. The most attractive bait (wheat bran) was used as the base for all subsequent studies. Preference for two different brands of wheat bran (Tree of Life and Arrowhead) was compared with determine whether size or shape of wheat bran flakes had any significance in preference. Tree of Life bran flakes are smaller than Arrowhead bran flakes. A petri dish containing the food source being tested was held at the same environmental conditions as the test materials. The amount of food consumed was measured in grams eaten and as a percentage of the total amount eaten per replicate. Four replicates of 10 grasshoppers per cage, with different starting times (days) serving as the basis for replication, were evaluated.

Oil Preference. A five-choice behavioral bioassay was used to test four different vegetable oils against a control to assess bait consumption. To prepare bait/oil mixtures, 3 g of wheat bran and 1 ml of canola (Publix), corn (Publix), peanut (Publix), or soybean oil (Hain Food Group, Inc., Uniondale, NY) were stirred in a beaker until incorporation was complete then transferred to a petri dish. Dishes containing bait/oil mixtures were randomly placed into cages with five male and five female adult eastern lubber grasshoppers. The grasshoppers were allowed to feed on the food source for 72 h. The environmental conditions were described above. The amount of food consumed was measured in grams eaten and as a percentage of the total amount eaten per replicate. Six replicates of 10 grasshoppers per cage were evaluated, with different starting times (days) serving as the basis for replication.

Flavor Extracts. A five-choice behavioral bioassay was used to test four different flavor extracts against a control to assess food source palatability and improve bait consumption. Four petri dishes were filled with 3 g of wheat bran coated with 1 ml each of banana (McCormick and Co., Inc., Hunt Valley, MD), lemon (Publix), anise (McCormick), or peppermint (McCormick) flavor extracts undiluted. Dishes were placed into cages with five male and five female adult eastern lubber grasshoppers. The grasshoppers were allowed to feed on the food source for 72 h. The conditions were the same as described above. The amount of food consumed was measured in grams eaten and as a percentage of the total amount eaten per replicate. Five replicates of 10 grasshoppers per

Table 1. Plant species evaluated in two-choice tests (vegetation versus wheat bran)

Family	Common name	Scientific name	Variety
Vegetable			
Solanaceae	Green bell pepper[a]	*Capsicum annuum* L.	*annuum*
Solanaceae	'Big Beef' tomato[a]	*Lycopersicon esculentum* Mill.	n/a
Solanaceae	'Black Beauty' eggplant[a]	*Solanum melongena* L.	n/a
Brassicaceae	Cauliflower[a]	*Brassica oleracea* L.	*botrytis*
Brassicaceae	'Vates' collards[a]	*Brassica oleracea* L.	*viridis*
Brassicaceae	Green cabbage[a]	*Brassica oleracea* L.	*capitata*
Cucubitaceae	Cantaloupe[a]	*Cucumis melo* Naudin	*cantalupensis*
Cucubitaceae	Cucumber[a]	*Cucurbita sativus* L.	*sativus*
Cucubitaceae	Yellow squash[a]	*Cucurbita pepo* L.	n/a
Asteraceae	'Butter Crunch' lettuce[a]	*Lactuca sativa* L.	*capitata*
Asteraceae	Red leaf lettuce[b]	*Lactuca sativa* L.	*capitata*
Asteraceae	Endive[b]	*Chichorium endivia* L.	*endivia*
Liliaceae	Green onion[b]	*Allium cepa* L.	*cepa*
Liliaceae	Leek[b]	*Allium porrum* L.	n/a
Liliaceae	Chive[a]	*Allium schoenoprasum* L.	n/a
Apiaceae	Carrot[b]	*Daucus carota* Hoffm.	*sativus*
Apiaceae	Parsley[a]	*Petroselinum crispum* Mill.	n/a
Apiaceae	Fennel[b]	*Foeniculum vulgare* Mill.	*Vulgare*
Ornamental			
Hemerocalidaceae	Daylily[a]	*Hemerocallis* spp. Hort.	n/a
Amaryllidaceae	Lily of the Nile[a]	*Agapanthus africanus* L.	n/a
Cannaceae	Canna lily[a]	*Canna flaccide* L.	n/a
Amaryllidaceae	Society garlic[a]	*Tulbhagia violacea* Harv.	n/a
Amaryllidaceae	Amaryllis[a]	*Hippeastratum* spp.	n/a
Araceae	Caladium[a]	*Caladium hortulanum* Birdsey	n/a

n/a, variety not known.
[a] Garden-grown plants.
[b] Purchased plants.

cage were evaluated, with different starting times (days) serving as the basis for replication.

Flavor Versus Oil. A four-choice behavioral bioassay was used to test the most preferred oil, the most preferred flavor extract, the combination of oil and flavor, and an untreated control to determine which was most palatable. The conditions are the same as for preference studies described above. The amount of food consumed was measured in grams eaten and as a percentage of the total amount eaten per replicate. Five replicates of 10 grasshoppers per cage were evaluated, with different starting times (days) serving as the basis for replication.

Storage of Bait. The effect of age on palatability of the bait also was tested. Consumption tests were conducted by placing four eastern lubber grasshoppers (two adults and two large nymphs) into 0.3 m^3 cages. Three petri dishes were placed randomly within the cage; one containing fresh bait of wheat bran and corn oil, one with aged bait of wheat bran and corn oil (corn oil and wheat bran mixture stored in a beaker covered with parafilm at room temperature for 4–8 wk), and a control of wheat bran with no oil. Environmental conditions were as described for grasshopper rearing. Five replicates of four grasshoppers per cage were evaluated. Grasshoppers were allowed to feed for 24 h and the amount of consumption measured by weight.

Vegetation Preference. Vegetable foliage and bait preferences were assessed using two-choice food preference tests. Four eastern lubber grasshoppers (two adults and two large fourth or fifth instars) were placed into 0.3 m^3 screen cages covered in plastic wrap to retain humidity. Feeding arenas were set up to simulate a natural setting. One arena was placed in each cage. Feeding arenas consisted of circular plastic containers (18 cm in diameter × 5 cm in height) filled three-quarters with builder's sand. A petri dish containing 3 g of a preferred bait matrix of wheat bran and corn oil was placed in the center of the arena. Four 15-ml conical polystyrene centrifuge tubes filled with water and one plant leaf were evenly placed surrounding the petri dish of bait matrix. The test tubes were wrapped in parafilm to provide stability of the vegetation in the test tube and to reduce evaporation of water in the test tubes. Plant material was either field collected fresh that day or purchased from a grocery store on the day of testing. In addition, for each treatment, a cage was set up identical to the test cage except that no grasshoppers were introduced. This cage served as a weight check to measure moisture loss or gain in each replicate. The grasshoppers were provided with no other food or source of moisture during the tests. The amount of bait consumed was measured in grams eaten and as a proportion of the total amount eaten per replicate.

Consumption tests were terminated when 50% of leaf foliage or bait matrix was consumed or 48 h passed, which allowed the grasshoppers sufficient opportunity to investigate the cage contents, sample the plants or bait, and make a measurable commitment to consumption of vegetation or bait without being forced onto a food source of secondary preference caused by depletion of the most preferred source.

Plant species evaluated in two-choice tests were several vegetables listed in Table 1. Environmental test conditions were as described for grasshopper rearing. Tests were replicated eight times for each type of vegetation.

Eastern lubber grasshoppers were tested for susceptibility to carbaryl under field conditions using outdoor cages. Six grasshoppers were placed into 1-m^3 hardware cloth cages. Grasshoppers had a choice of feeding on carbaryl-treated wheat bran and oil (or untreated wheat bran in the control), lawn grass, and various cultivars of daylilies, *Hemerocallis* spp. The carbaryl bran bait was placed in two petri dishes on the floor of the cage. The grasshopper could feed on the bait, blades of bahiagrass, *Papsalum notatum* Flugge, which protruded into the cage or daylily that were in two pots within the cage. There were five treatment and five control cages each containing six adult or late instar grasshoppers. Carbaryl was applied to the wheat bran (10% wt:wt) by first dissolving technical grade carbaryl in acetone and adding wheat bran to the mixture. The acetone was evaporated before corn oil was added to the carbaryl-coated wheat bran. The tests were conducted in June and July 2001, and number of dead grasshoppers was tabulated after 72 h.

Effect of Bait Consumption Level on Mortality. To assess how many flakes of carbaryl-treated bran should be consumed to cause mortality, adult eastern lubber grasshoppers were offered various numbers of treated bran flakes. Carbaryl at 10% concentration was used for all treatments except the untreated control, and 5 d of exposure was allowed to elapse before mortality was tabulated. Grasshoppers were caged individually in circular plastic containers (18 cm in diameter × 5 cm in height) and held at 30°C in a room with fluorescent and incandescent lighting on a 14-h diurnal photoperiod. Eastern lubber grasshoppers were offered zero (control), one, two, three, four, or five treated flakes over a 5-d period. Five replicates were completed for each treatment level.

Data Analysis. Data were analyzed using a one-way analysis of variance (ANOVA). Bran brand data were analyzed using a paired *t*-test. Vegetable consumption data (%) and vegetable family consumption data (%) were transformed using square-root transformation. Mortality in field cage tests was log (x) transformed and analyzed using a paired *t*-test. When appropriate, comparisons among treatments were determined using Tukey–Kramer multiple comparison test (P = 0.05) with InStat (InStat 1993).

Table 2. Bait matrix consumption by eastern lubber grasshoppers after 72 h

Food Source	Consumption	
	(% ± SE)	(g ± SE)
Corn flakes	1.65 ± 0.72a	0.04 ± 0.02a
Yeast	6.17 ± 2.07ab	0.07 ± 0.03ab
Oat bran	14.96 ± 2.14ab	0.35 ± 0.13ab
Corn meal	20.57 ± 1.68bc	0.53 ± 0.23ab
Rolled oats	20.86 ± 5.21bc	0.46 ± 0.15ab
Wheat bran	36.54 ± 6.63c	0.94 ± 0.36b

Means ± SE followed by the same letter are not significantly different (P = 0.05) by the Tukey-Kramer multiple comparison test. ANOVA statistics are F = 11.04; df = 5,29; P < 0.0001 for consumption (%) and F = 3.03; df = 5,29; P = 0.0292 for consumption (grams).

Table 3. Consumption of three most preferred bait matrices by eastern lubber grasshoppers after 72 h

Food source	Consumption	
	(% ± SE)	(g ± SE)
Rolled oats	21.99 ± 4.42a	0.48 ± 0.08a
Oat bran	27.92 ± 5.36a	0.57 ± 0.09a
Wheat bran	50.09 ± 5.21b	1.08 ± 0.20b

Means ± SE followed by the same letter are not significantly different (P = 0.05) by the Tukey-Kramer multiple comparison test. ANOVA statistics are F = 8.72; df = 2,14; P = 0.0046 for consumption (%) and F = 4.59; df = 2,14; P = 0.0331 for consumption (grams).

Results

Matrix Preference. Significant differences in bait matrix consumption were noted (Table 2). Wheat bran, rolled oats, and corn meal were the preferred food items. Corn meal, even though preferred, was not used in subsequent tests because of the small size of the grain. These foods were then tested against each other and the wheat bran was consumed in greater quantity than the oat bran and rolled oats (Table 3). The effects of different size and shape of wheat bran flakes were analyzed using two-choice behavioral bioassays with different brands of wheat bran flakes (Tree of Life and Arrowhead brands). Percent consumption of Tree of Life was 44.53 ± 9.49 Arrowhead brand percent consumption was 54.73 ± 10.17. Brand of wheat bran carrier did not influence grasshopper preference [t = 0.2702; F = 1.12; df = 6; P = 0.7691 for consumption (%) and t = 0.1727; F = 1.12; P = 0.8686 for consumption (grams)].

Oil Preference. There was greater consumption of wheat bran treated with oil than without oil (Table 4). There were no significant differences among the four oils tested based on weight consumed. Based on percentage of consumption, grasshoppers had equivalent preferences for canola, peanut, and corn oils, but bait treated with soybean oil was consumed less than bait treated with corn or peanut oil. Bait treated with corn oil was most preferred.

Flavor Extracts. Addition of banana flavoring to the wheat bran carrier resulted in greater feeding than the wheat bran carrier alone or addition of peppermint flavoring (Table 5). None of the other flavorings were more stimulatory to feeding than the control.

Table 4. Consumption of wheat bran containing various oils by eastern lubber grasshoppers after 72 h of exposure

Oil	Consumption	
	(% ± SE)	(g ± SE)
Control[a]	1.39 ± 0.86a	0.04 ± 0.03a
Soybean	17.10 ± 2.64b	0.37 ± 0.05ab
Canola	21.93 ± 3.51bc	0.50 ± 0.10b
Peanut	27.84 ± 3.53c	0.63 ± 0.09b
Corn	31.74 ± 5.05c	0.74 ± 0.17b

Means ± SE followed by the same letter are not significantly different (P = 0.05) by the Tukey-Kramer multiple comparison test. ANOVA statistics are F = 12.03; df = 4,29; P < 0.0001 for consumption (%) and F = 7.17; df = 4,29; P = 0.0005 for consumption (grams).

[a] Wheat bran with no oil additive.

Table 5. Consumption of wheat bran containing various imitation flavorings by eastern lubber grasshoppers after 72 h

Flavoring	Consumption	
	(% ± SE)	(g ± SE)
Control[a]	7.86 ± 3.51a	0.09 ± 0.04a
Peppermint	6.08 ± 2.53a	0.08 ± 0.05a
Anise	20.61 ± 2.58ab	0.19 ± 0.03ab
Lemon	24.56 ± 8.64ab	0.21 ± 0.05ab
Banana	40.90 ± 9.22b	0.42 ± 0.14b

Means ± SE followed by the same letter are not significantly different ($P = 0.05$) by the Tukey-Kramer multiple comparison test. ANOVA statistics are $F = 5.40$; df = 4,24; $P = 0.0041$ for consumption (%) and $F = 3.10$; df = 4,24; $P = 0.0388$ for consumption (grams).

[a] Wheat bran with no flavor additive.

Flavor versus Oil. Addition of corn oil to the wheat bran carrier induced significantly more feeding activity than addition of banana flavor, the combination of banana flavor and corn oil, and the wheat bran carrier alone (Table 6). The consumption of the carrier alone, and the carrier containing the combination of banana and corn oil, and the banana flavoring were not significantly different.

Storage of Bait. Bait age affected percentage of consumption (Table 7). When assessed by percentage of consumption, older bait (≥1 wk old) was more preferred than freshly prepared wheat bran and corn oil, or wheat bran alone. When assessed by grams of bait consumed, there were no significant differences.

Vegetation Preference. Significant differences in bait consumption in the presence of different vegetable plants were noted (Table 8). On average, vegetables in the families Solanaceae and Apiaceae elicited high levels of bait feeding activity (Table 9). The plants tested from the families Liliaceae, Cucurbitaceae, Asteraceae, and Brassicaceae elicited an intermediate to low level of bait feeding. Significant differences in bait consumption in the presence of ornamental plants were noted (Table 10). Grams of bait consumed were low in the presence of society garlic, amaryllis, and caladium. Daylily was intermediate.

Field Cage Tests. The 10% carbaryl wheat bran/oil bait caused mortality in eastern lubber grasshopper relative to the control ($t = 5.114$; $F = 3.1572$; df = 8; $P = 0.1458$), with ≈50% mortality induced by exposure for 3 d.

Table 6. Consumption of wheat bran containing various additives by eastern lubber grasshoppers after 72 h

Additive	Consumption	
	(% ± SE)	(g ± SE)
Banana flavoring	13.29 ± 3.92a	0.20 ± 0.07a
Banana flavoring + corn oil	13.59 ± 4.38a	0.21 ± 0.08a
Control	14.36 ± 6.88a	0.15 ± 0.07a
Corn oil	58.76 ± 6.09b	0.76 ± 0.12b

Means ± SE followed by the same letter are not significantly different ($P = 0.05$) by the Tukey-Kramer multiple comparison test. ANOVA statistics are $F = 17.04$; df = 3,19; $P < 0.0001$ for consumption (%) and $F = 10.45$; df = 3,19; $P = 0.0005$ for consumption (grams).

Table 7. Consumption of wheat bran and corn oil bait carriers of differing freshness by eastern lubber grasshoppers after 24 h of feeding

Food Source	Consumption	
	(% ± SE)	(g ± SE)
Wheat bran	14.15 ± 5.37a	0.05 ± 0.02a
Freshly prepared food source	33.07 ± 8.13a	0.13 ± 0.05a
Bait prepared >1 wk	52.78 ± 8.05b	0.16 ± 0.03a

Means ± SE followed by the same letter are not significantly different ($P = 0.05$) by the Tukey-Kramer multiple comparison test. ANOVA statistics are $F = 7.01$; df = 2,14; $P = 0.0096$ for consumption (%) and $F = 3.16$; df = 2,14; $P = 0.0790$ for consumption (grams).

Effect of Bait Level Consumption on Mortality. When eastern lubber grasshoppers were fed an insecticide-treated bait, mortality was 0% among grasshoppers fed zero bran flakes, but was 100, 80, 40, 60, and 80% when fed one, two, three, four, and five flakes of 10% carbaryl-treated bran, respectively.

Discussion

The results of this study showed that when offered a choice, eastern lubber grasshopper adults and late instars preferred bait consisting of wheat bran carrier with corn oil as an added phagostimulant. Wheat bran is known to be an effective bait carrier to several species of grasshoppers and other insects with similar feeding patterns (Cooley et al. 1918, Farrar and Flint 1938, Shotwell 1942, Martin 1980) and seems to be an acceptable bait carrier for the eastern lubber grasshopper.

Bomar and Lockwood 1994b, reported that addition of linoleic and linolenic acid to carbaryl bran bait significantly lowered rangeland grasshopper popula-

Table 8. The consumption of wheat bran containing corn oil in the presence of different garden vegetables by *R. guttata* after 50% of leaf matter consumed or 48 h

Vegetable	Bait consumption	
	(g ± SE)	(% ± SE)
Butter crunch lettuce	0.07 ± 0.03d	0.65 ± 0.26c
Carrot	0.22 ± 0.09cd	2.46 ± 1.04bc
Yellow squash	0.31 ± 0.08cd	2.91 ± 0.69bc
Cauliflower	0.27 ± 0.10cd	2.55 ± 0.90bc
Collards	0.32 ± 0.12bcd	3.08 ± 2.20bc
Green onion	0.47 ± 0.11abcd	4.38 ± 0.90abc
Chive	0.48 ± 0.09abcd	5.05 ± 1.11abc
Cucumber	0.49 ± 0.05abcd	5.02 ± 0.74abc
Cabbage	0.49 ± 0.12abcd	5.08 ± 1.43abc
Cantaloupe	0.49 ± 0.14abcd	4.59 ± 1.12abc
Endive	0.54 ± 0.14abcd	5.30 ± 1.33abc
Red leaf lettuce	0.59 ± 0.19abcd	5.78 ± 1.89abc
Eggplant	0.66 ± 0.40abcd	6.28 ± 1.14abc
Pepper	0.73 ± 0.55abc	9.52 ± 2.08ab
Leek	0.97 ± 0.10ab	9.59 ± 0.91a
Parsley	0.99 ± 0.17a	9.52 ± 1.75a
Tomato	1.00 ± 0.15a	10.13 ± 1.77a
Fennel	1.04 ± 0.15a	10.30 ± 1.43a

Means ± SE followed by the same letter are not significantly different ($P = 0.05$) by the Tukey-Kramer multiple comparison test. ANOVA statistics are $F = 5.07$; df = 17,143; $P < 0.0001$ for consumption (g) and $F = 5.62$; df = 17,143; $P < 0.0001$ for consumption (percent).

Table 9. Consumption by eastern lubber grasshoppers of wheat bran containing corn oil in the presence of different vegetable families

Family	Bait consumption	
	(g ± SE)	(% ± SE)
Brassicaceae	0.36 ± 0.07	3.57 ± 0.77
Asteraceae	0.40 ± 0.17	3.91 ± 1.63
Cucurbitaceae	0.43 ± 0.06	4.17 ± 0.64
Liliaceae	0.64 ± 0.17	6.34 ± 1.64
Apiaceae	0.75 ± 0.27	7.43 ± 2.49
Solanaceae	0.80 ± 0.10	7.92 ± 1.15

Means ± SE: ANOVA statistics are $F = 1.50$; df = 5,17; $P = 0.2584$ for consumption (grams) and $F = 1.23$; df = 5,17; $P = 0.3545$ for consumption (percent).

tions compared with carbaryl bran bait alone. In the current study, bait additives such as corn oil and banana flavoring stimulated feeding by *R. guttata;* however, oil additives were preferred over the flavorings, possibly indicating a preference for lipid-based materials by *R. guttata.* Corn oil contains a large amount of linoleic acid compared with the other oils tested in this study: 34–62% in corn oil, 21% in canola, 49% in soybean, 26% in peanut (Windholtz et al. 1976). Adding a vegetable oil such as corn oil to wheat bran formulations is an economic way to improve the effectiveness of wheat bran baits.

Appearance and size of the bran flakes vary among different brands. The results of different brands of wheat bran tested showed that appearance and size of flakes were not significant factors influencing palatability of bran baits by *R. guttata.* Eastern lubber grasshoppers showed no preference toward a certain flake shape or size, because Tree of Life brand, which was a small flake size (≤2 mm), was consumed at the same frequency as Arrowhead brand, which was a large flake size (2–4 mm). Hence, varying sizes of wheat bran flakes would likely be effective when making wheat bran bait for an eastern lubber grasshopper infestation.

The age of the bait affected the palatability to grasshoppers. When allowed to age for ≥4 wk the wheat bran/oil bait was more palatable to grasshoppers. Thus, a large batch of bait can be prepared and any remaining bait not used in the application can be stored and used at a later date, though it probably cannot be stored indefinitely.

Table 10. The consumption of wheat bran containing corn oil in the presence of different ornamental plants by *R. guttata* after 50% of leaf matter consumed or 48 h

Ornamental Plant	Bait consumption	
	(g ± SE)	(% ± SE)
Society garlic	0.30 ± 0.10a	8.20 ± 2.26a
Caladium	0.37 ± 0.11a	9.59 ± 2.07a
Amaryllis	0.39 ± 0.07a	11.10 ± 1.95a
Daylily	0.60 ± 0.18ab	14.96 ± 3.96a
Canna lily	0.94 ± 0.14b	26.44 ± 3.98b
Lily of the Nile	1.04 ± 0.05b	29.69 ± 2.47b

Means ± SE followed by the same letter are not significantly different ($P = 0.05$) by the Tukey-Kramer multiple comparison test. ANOVA statistics are $F = 7.52$; df = 5,46; $P < 0.0001$ for consumption (g) and $F = 9.93$; df = 5,46; $P < 0.0001$ for consumption (percent).

Banana flavoring, which is banana oil in an alcohol solution, has been used previously as an insect feeding stimulant (Parker 1922, Swenk and Wehr 1923, Shotwell 1942). In this study, banana flavoring stimulated feeding compared with peppermint flavorings. Banana also stimulated feeding compared with wheat bran alone. Banana stimulated the most feeding over the other flavors tested when measured as percent age of consumption of bait. However, banana flavoring proved ineffective in stimulating feeding compared with corn oil and the combination of corn oil and banana flavor. Peppermint flavoring was sampled only rarely and may have been acting as a deterrent because it was sampled and not avoided completely.

Although highly polyphagous, *R. guttata* demonstrated clear preference for certain species of plants relative to bait. The bait matrix was readily consumed when in the presence of some plant species but others. Vegetables of the same family were often of similar preference to *R. guttata.* Thus, we could expect to obtain higher levels of grasshopper mortality in the presence of vegetables in the families Solanaceae and Apiaceae because grasshoppers were not prone to feed extensively on these crops. Several of the vegetables tested, including cucumber, cantaloupe, cabbage, red leaf lettuce, endive, green onion, and chive, were of intermediate preference. Among the most preferred vegetable crops, and thus least effectively defended against consumption by eastern lubber grasshopper, were lettuce, squash, carrot, cauliflower, and collards.

The wheat bran and corn oil bait may prove effective in a garden containing these vegetables if placed in a location such as the perimeter where the grasshoppers would encounter it before the plant material. We expect that wheat bran and corn oil bait would be most effective as protection for tomato, pepper, eggplant, leek, parsley, and fennel.

Eastern lubber grasshopper showed significant preference for society garlic, amaryllis, and caladium compared with wheat bran/corn oil bait and seemed to prefer the bait over daylily, lily of the Nile, and canna lily. The wheat bran and corn oil bait may be effective in protecting canna lily, lily of the Nile and daylily from eastern lubber grasshopper infestations but may be less effective in protecting society garlic, amaryllis, and caladium. For a well-designed garden plan, it may be advantageous to place the less preferred plants on the perimeter, protecting them with the wheat bran corn oil bait, and to place most of the more preferred plants such as society garlic, amaryllis, and canna lily in the inner region of the garden. This requires further study and should be tested.

The carbaryl wheat bran and oil bait was effective at causing eastern lubber grasshopper mortality. There was significant mortality even though grasshoppers had to locate dishes of bait in a large cage, and could feed on daylilies, or grass growing through the bottom of the cage, rather than on the bran flakes. Thus, it is possible that effective eastern lubber grasshopper suppression can be attained under field conditions in the presence of some not highly preferred garden plants. The low level of mortality caused by carbaryl in field cage tests was not surprising. Eastern lubber grasshoppers are difficult to kill with insecticides, but more effective materials could be identified.

Individual grasshoppers may have the opportunity to consume only a few particles of bran if bran bait is scattered widely and at a low density, or if grasshoppers are extremely numerous and competing for the bran resource. Therefore, it is beneficial to know what doses of toxicant are adequate to kill a high proportion of individual grasshoppers. Ingestion of only one flake of 10% carbaryl-treated wheat bran caused high mortality in the eastern lubber grasshopper, although ingestion of bran did not always kill eastern lubber grasshoppers, including those that consumed more than one flake of insecticide-treated bran. One explanation for this is that susceptibility to the toxicant in each individual grasshopper may vary. Another explanation for incomplete mortality may be because of uneven treatment of the bait with the toxicant.

Overall, the carbaryl, wheat bran, and corn oil bait was effective in causing mortality to eastern lubber grasshoppers over a period of several days. The bait is easily formulated with materials readily available, and relatively inexpensive. A toxic wheat bran and corn oil bait could be advantageous when used as a perimeter treatment to protect plants from an eastern lubber grasshopper infestation.

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